9.10 Power-Related Facilities

9.10.1 Power Supply Installation

(1) Basic Method

As discussed in Chapter 4, the basic plan for the power supply installation (PSI) is as follows.

- Incoming Method
  It is powered by double lines taken from the transmission network of 132/220kV, which is the main transmission system of Electric Power companies.
- Feeding system
  The feeding system will be single-phase AC, 50Hz, 2x25kV.
- Feeding Voltage
  The standard voltage of the system is 25kV. The maximum allowable voltage is 30kV and minimum allowable voltage is 22.5kV. In addition, there is a minimum voltage of 20kV for short durations.
- Substation System
  The substation system shall be as follows:
  There will be a spacing of 50 to 60km between the traction substations (TSS).
  There will be 25 to 30km interval between TSS and the sectioning and paralleling post (SP). And, there will be sub-sectioning and paralleling post (SSP) in the midway of the SP and TSS.

(2) Connection Method of Traction Transformers

The connection methods of traction transformer are Scott connection method and the V- connection method. The connection method is shown in Figure 9.10-1 and Figure 9.10-2 respectively.

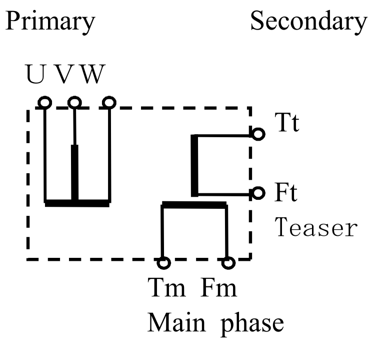
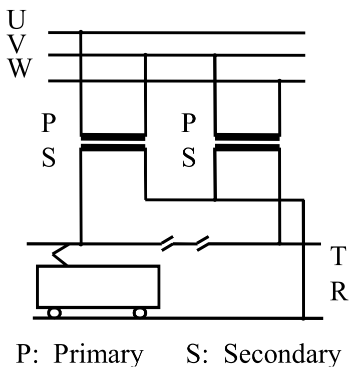


Figure 9.10-1 Scott Connection Method



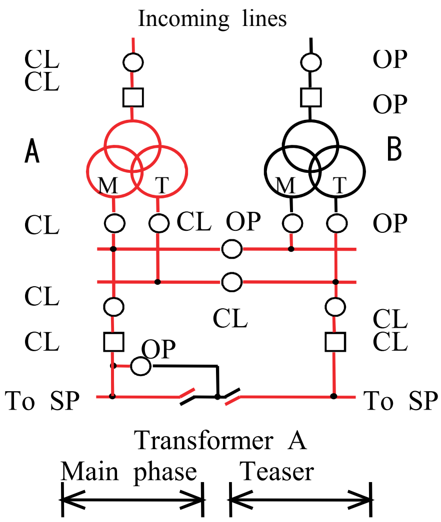
Source Study team

Figure 9.10-2 V-connection Method

1) Connection of Feeding Transformers and Operating Method

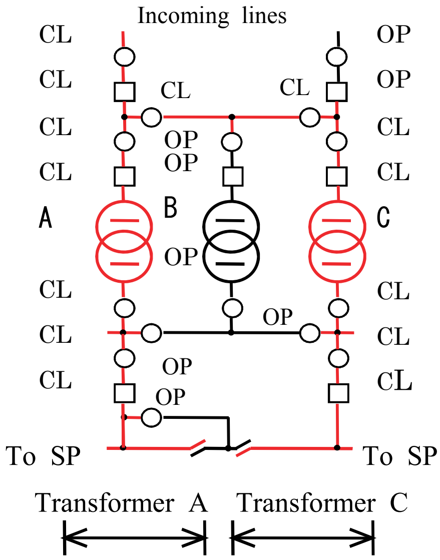
Scott connection method is installed using two transformers, one for operation and other for stand-by, as shown in Figure9.10-3.

V-connection method is installed using three transformers, two for operation and third for stand-by, as shown in Figure 9.10-4.



CL: Close OP: Open

Figure 9.10-3 Operating of Scott Connection



CL: Close OP: Open

Source Study team

Figure 9.10-4 Operating of V-connection

2) Connection Method of Traction Transformers and Voltage Unbalance Rate

The following formula is used for calculating voltage unbalance rate due to the connection method of the transformers.

a) Single phase transformer

$u=(Es\times I)/Ps)\times 100$ (%)

b) V-connection transformer

$u=(Es\times SQR(Ia^2+Ib^2-Ia\times Ib)/Ps)\times 100$(%)

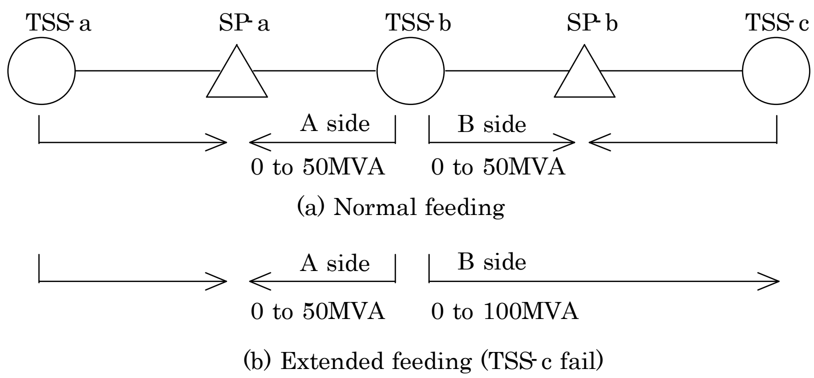
c) Scott connection transformer

$u=(Es\times|(Im-It)|/Ps)\times 100$(%)

However,	u	: Voltage unbalance rate	(%)
	Es	: Line voltage	(kV)
	Ps	: Short current apparent power	(kVA)
	I	: Line current (Single phase)	(A)
	Ia、Ib	: Line current (V-connection)	(A)
	Im、It	: Line current (Scott connection)	(A)

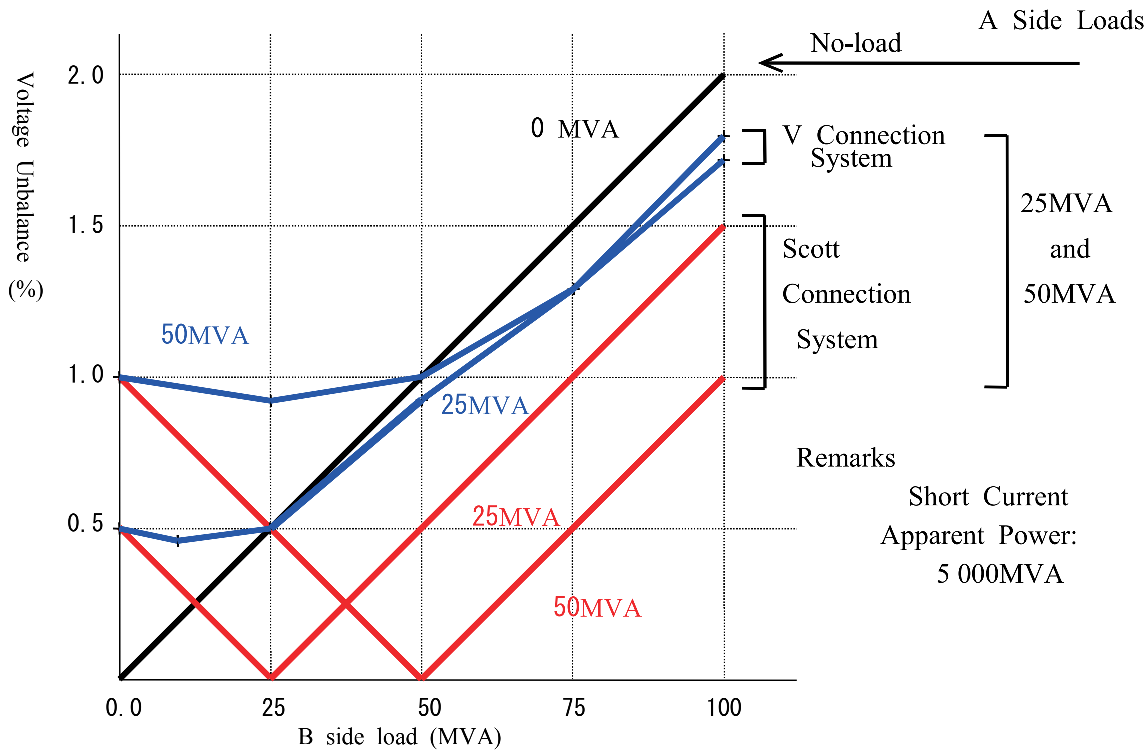
3) Calculation of Voltage Unbalance Rate

The calculation is done depending on the load conditions as shown in Figure 9.10-5. The Figure 9.10-6 shows the calculation result of the unbalanced rate. Voltage unbalance rate is the same in any connection when the load in one direction only. However, if there are loads in both directions, the unbalanced rate is smaller than V-connection in case of Scott connection.



Source Study team

Figure 9.10-5 Load Conditions



Source: Study team

Figure 9.10-6 Connection Method of Traction Transformers and Voltage Unbalance Rate

4) Connection Methods adopted for high-speed rail

Table 9.10-1 shows the connection methods adopted for different high-speed rails. South Korea high-speed rail (KTX) was constructed by introducing the technology of France. However, Scott connection method is same as used for Shinkansen in Japan.

Table 9.10-1 Connection Methods Adopted for High-speed Rail

Type of Connection Method	Name of Country
Scott Connection	Japan, Taiwan, South Korea
V-connection	France, Spain, U.K., Italy, China

Source: Study team

5) Recommendation

Scott connection method is proposed for the following reasons.

a) The incoming circuit can be simplified.
b) The number of traction transformers is reduced.
c) The power supply voltage unbalance is reduced.

(3) System Voltage and Voltage Regulation

Table 9.10-2 shows the system voltage and voltage regulations. The highest voltage is same for Indian railways and Shinkansen. However, the minimum voltage is higher to ensure the power supply to the Shinkansen train.

Table 9.10-2 System Voltage and Voltage Regulation

Name of Country	Kinds of Lines	Nominal voltage (kV)	Maximum voltage (kV)		Minimum voltage (kV)	
			Short term	Continuous	Continuous	Short term
Japan	Shinkansen (High-Speed)	25.0	---	30.0	22.5	20.0
India	Conventional	25.0	30.0	27.0	18.5	17.5
IEC		25.0		27.5	19.0	17.5

Source: Study team

(4) Plan of Incoming Lines

1) Incoming Voltage

Table 9.10-3 shows Incoming voltage of traction substation (TSS) that has been adopted for Indian Railways. The 132/220kV system is desirable as the incoming voltage for the high-speed rail. The reason, short current apparent power is larger than that of the 66kV to 132/220kV. There is also an advantage that voltage unbalance rate is reduced by this.

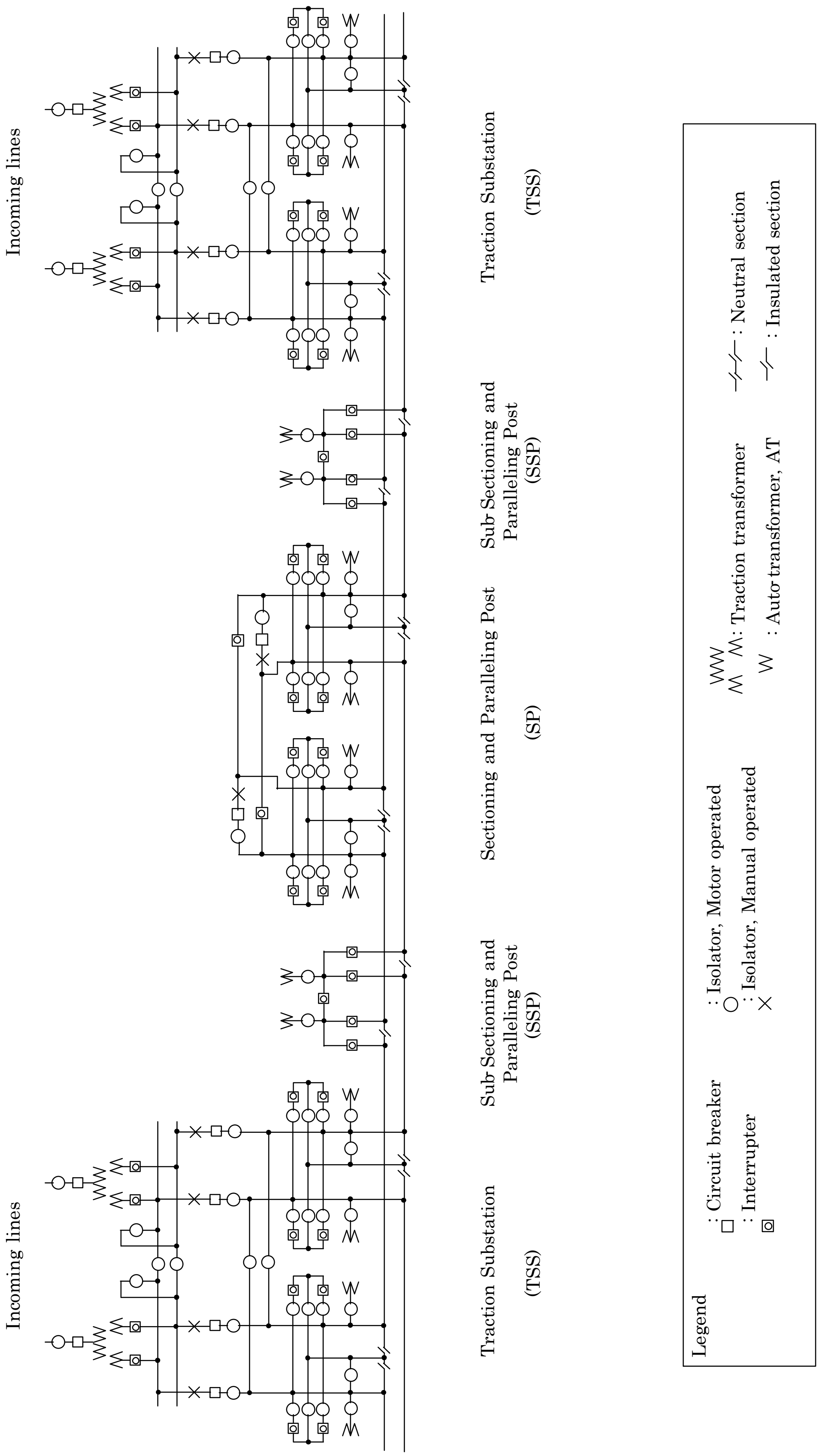
Table 9.10-3 Incoming Voltages of TSS

System voltage (kV)	66kV, 110kV, 132kV, 220kV

Source: Study team

(5) Passing method for Neutral Section

For passing neutral section (NS), changeover section system is adopted in which there is no effect on operation of trains. In this system, the train is also the regenerative breaking or powering, can pass directly.



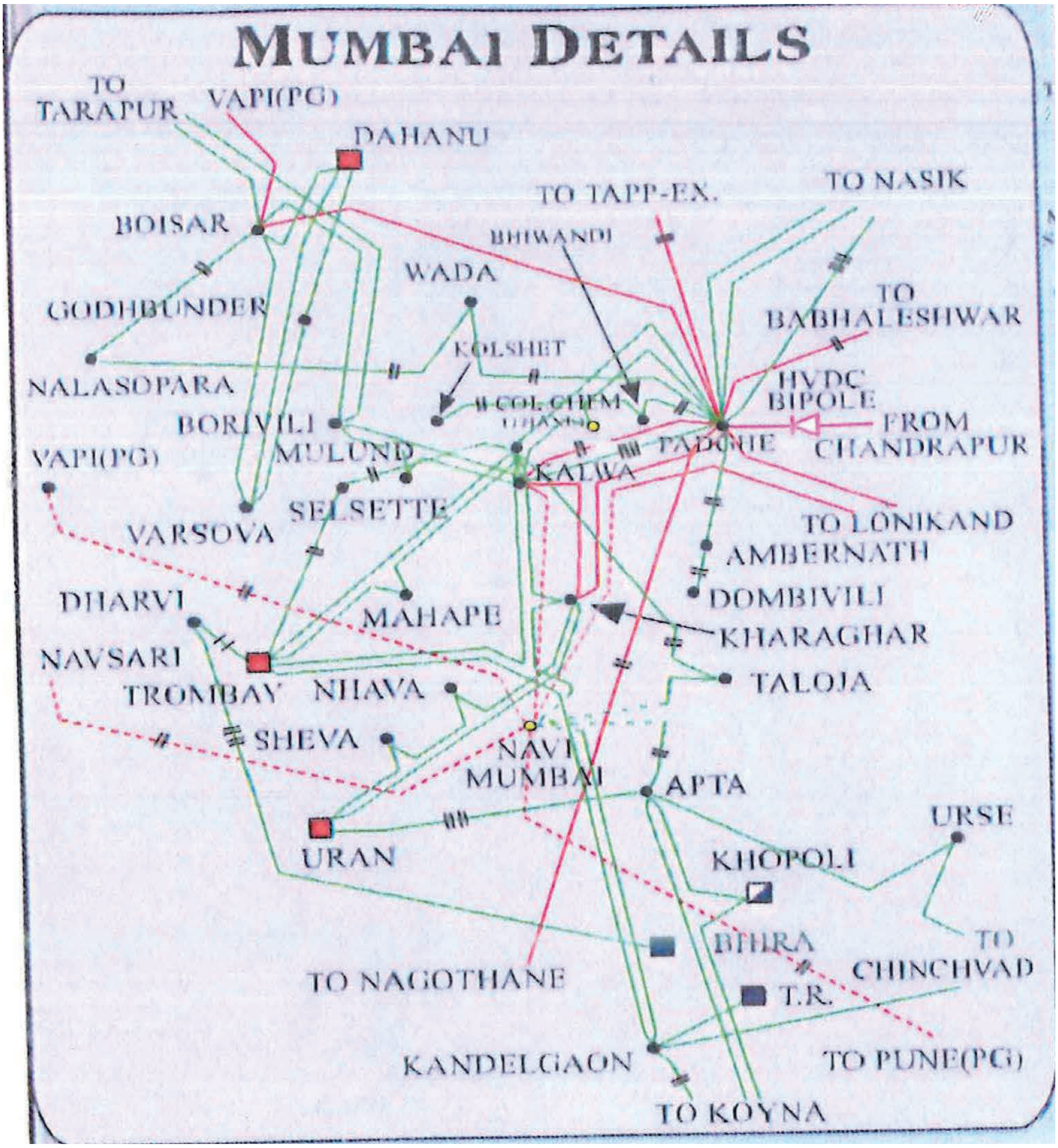
Source: Study team

Figure 9.10-7 Standard Power Supply Network

(6) Incoming Plan

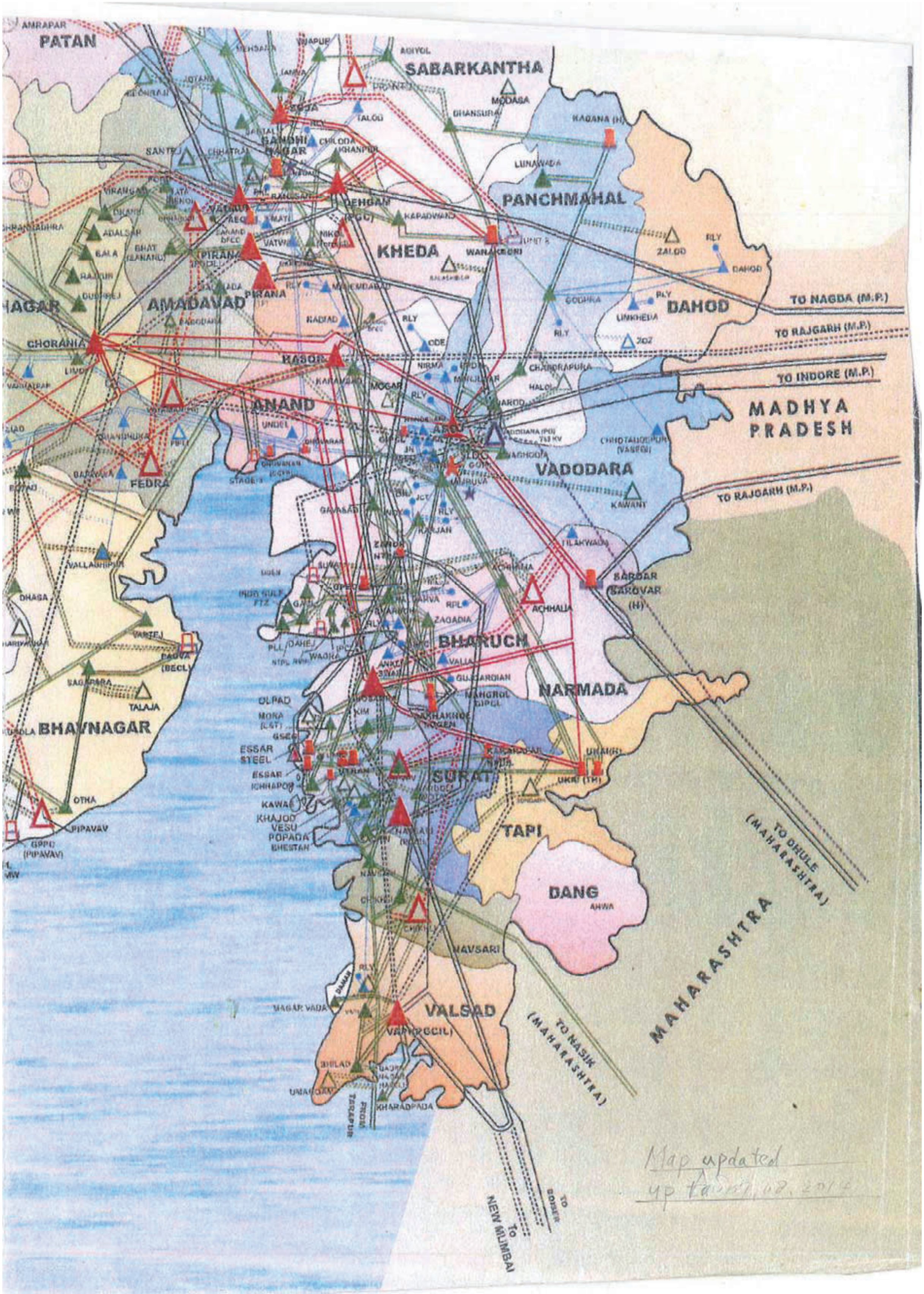
For the incoming plan, the incoming voltage is taken as 132/220kV. Scott connection method is proposed because it gives only small voltage unbalance to the power source, when compared to the V connection method. Japan, Taiwan and Korea have adopted the Scott connection.

The power transmission map of Mumbai and Gujarat is shown in Figure 9.10-8 and Figure 9.10-9 respectively. The transmission system of the Power Authority in the project area is 66/132/220/400kV. The supply to TSS for high-speed rail will be coming from the grid substations (GSS) or the power stations (PS) of the Power Authority.



Source: Major Transmission Network of India,
Central Electricity Authority

Figure 9.10-8 Power Map of Mumbai Details



Source: Gujarat Energy Transmission Corporation Limited

Figure 9.10-9 Power Map of Gujarat (Project Section)

On the basis these maps, the locations of TSS are shown in Table 9.10-4, when the distance between the TSS is set to 50 to 60 km interval.
For determining the exact locations of TSS, field surveys are required to check whether it is possible to draw transmission circuits from the GSS/PS or if there is any obstruction in the route of transmission lines to the planned TSS sites.

Table 9.10-4 Location Plan of Traction Substations (Tentative)

No	Traction Substation (TSS) Name	Total Length (km)	Grid Substation (GSS) or Power Station (PS) of Power Supply Authority
01	Mumbai	7	Muland/GSS
02	Virar	59	Vasai/GSS
03	Boisar	114	Dahanu/PS
04	Vapi	167	Vapi(new)/GSS
05	Bilimora	220	Ambipa/GSS (New)
06	Surat	275	Utran/PS
07	Bharuch	330	Vadidla/GSS
08	Vadodara	385	Jambura/GSS
09	Anand	440	Karmsad/GSS
10	Ahmedabad	492	Vatwa/GSS (132kV)

A field survey was conducted from Ahmedabad to Mumbai to confirm the plan shown in Table 9.10-4. From the results of the field survey, it was found that it is possible to provide power to all the ten TSS locations, although some locations were found to be different than originally expected. The final incoming point will be decided by discussions with the Power Authority, and the incoming plan prepared here could be an important document for the discussions.

Here is an example from the field survey. This example is for Vapi/TSS. As per the map, the Vapi/GSS is a 132/220kV GSS. Figure 9.10-10 shows the surrounding area near Vapi. However from the field survey, Study team came to know that it is actually a 66kV Electricity Board SS (EBSS) as shown in Figure 9.10-11. So Study team surveyed the area and were able to find a 400/220kv station of Power Grid Corporation of India LTD (PGCIL) as shown in Figure 9.10-12 and 9.10-13. As per the map, this station was located at far-east of Vapi city, however for the field survey Study team found out that it is only 15 min from the 66kV EBSS.

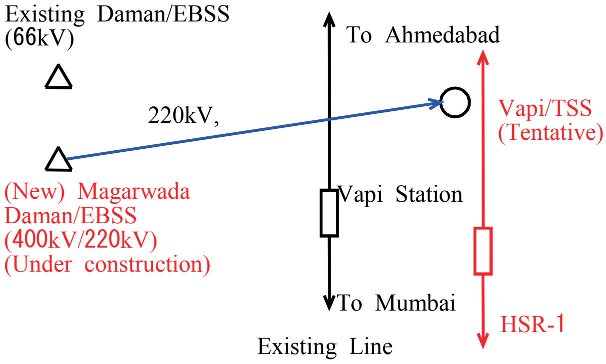


Figure 9.10-10 Location Map of Vapi

Figure 9.10-11 Daman/EBSS

Figure 9.10-12 Vapi/PGCIL/SS

Source: Study team

Figure 9.10-13 400kV Incoming Lines

Figure 9.10-14 shows the minimum distance of transmission line from GSS/PS, the location of SP at midpoint and the name of proposed HSR station. The location of each TSS/SP/SSP and the distance between them is shown in Figure 9.10-15.

As per the arrangement shown in Figure 9.10-16, the spacing between each TSS will be 50 to 55 km and spacing between each post will be about 13-14 km. These spacing are within the desirable spacing of 50-60 km for TSS and 13-17 km for each posts.

GSS or PS of Power Supply Authority	Muland Vasai Dahanu/PS Vapi（New） Ambipa
Minimum Distance of Incoming line	8km 7 km 2km 9km 13km
Traction Substation Name	01_Mumbai 7km 02_Virar 59km 03_Boisar 114km 04_Vapi 167km 05_Bilimora 220km
Station Name	Mumbai 0.0km Thane 27.9km Virar 64.9km Boisar 104.4km Vapi 168.9km Bilimora 217.3km

GSS or PS of Power Supply Authority	Utran/PS Vadadla Jambura Karmsad Vatwa (132kV)
Minimum Distance of Incoming line	12km 2km 2km 6km 2km
Traction Substation Name	06_Surat 275km 07_Bharuch 330km 08_Vadodara 385km 09_Anand 440km 10_Ahmedabad 492km
Station Name	Surat 264.5km Bharuch 323.1km Vadodara 396.9km Anand/Nadiad 447.1km Ahmedabad 499.8km Sabarmati 505.4km 507km Workshop

Remarks   GSS : Grid Substation   PS : Power Station

Source: Study team

Figure 9.10-14 Map of Planned Traction Substations (Tentative)

Station Name	TSS Name	SP Name	SSP Name	Total Length (km)	TSS Interval (km)	TSS to SP Interval (km)	Post to Post Interval (km)
Mumbai				0			
	01_Mumbai			7			7
			21	21		26	14
Thane				27.9			
		11		33	52		12
			22	46		26	13
	02_Virar			59			13
Virar				64.9			
			23	72.75		27.5	13.75
		12		86.5	55		13.75
			24	100.25		27.5	13.75
Boisar				104.4			
	03_Boisar			114			13.75
			25	127.25		26.5	13.25
		13		140.5	53		13.25
			26	153.75		26.5	13.25
Vapi				168.9			
	04_Vapi			167			13.25
			27	180.25		26.5	13.25
		14		193.5	53		13.25
			28	206.75		26.5	13.25
Bilimora				217.3			
	05_Bilimora			220			13.25
			29	233.75		27.5	13.75
		15		247.5	55		13.75
			30	261.25		27.5	13.75
Surat				264.5			
	06_Surat			275			13.75
			31	288.75		27.5	13.75
		16		302.5	55		13.75
			32	316.25		27.5	13.75
Bharuch				323.1			
	07_Bharuch			330			13.75

Source: Study team

Figure 9.10-15 Location Plan of TSS/SP/SSP (Tentative)(1/2)

Station Name	TSS Name	SP Name	SSP Name	Total Length (km)	TSS Interval (km)	TSS to SP Interval (km)	Post to Post Interval(km)
	07_Bharuch			330			13.75
			33	343.75		27.5	13.75
		17		357.5	55		13.75
			34	371.25		27.5	13.75
	08_Vadodara			385			13.75
Vadodara				396.9			
			35	398.75		27.5	13.75
		18		412.5	55		13.75
			36	426.25		27.5	13.75
	09_Anand			440			13.75
Anand/ Nadiad				447.1			
			37	453		26	13
		19		466	52		13
			38	479		26	13
	10_Ahmedadad			492			13
Ahmedbad				499.8			
Sabarmati				505.4			
			39	506			14

Source: Study team

Figure 9.10-16 Location Plan of TSS/SP/SSP (Tentative)(2/2)

(7) Substation Facility Planning

The Indian Railways has 18 years of experience in operating the 2x25kV feeding system for the 724 km long Bina – Katni – Anupur - Bishrampur/Chirimiri line which was opened in the year 1996. Also, the 2,635km long Dedicated Freight Corridor (DFC) project, which is under construction, has adopted the 2x25kV system. Here, the 2x25kV system is compared with the conventional system with regard to the system requirements for the High speed rail.
There is a need to increase the capacity of transformer substation facility, of which there is the auto-transformer (AT) and traction transformer (TTr). In addition, Study team proposes to adopt the changeover switch. These are described as follows.

1) Traction Transformer

Maximum power current of conventional lines is 600A to 700A as compared to 1000A for High speed rails. Therefore, it is necessary to have larger traction transformer capacity for HSR-1 than for the conventional lines. The traction transformer capacity is 50MVA (2x25MVA) in Conventional lines but, 120MVA (2x60MVA) is required in HSR-1.
If fluctuations in the incoming voltage is large traction substation, installed the OLTC (On-load tap changer).

2) Auto Transformer

It is necessary to increase the capacity of auto transformer (AT) for the same reason as traction transformer. For this reason, AT capacity is 8MVA in conventional lines but 15MVA for HSR-1.

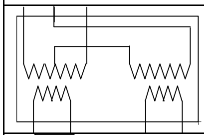
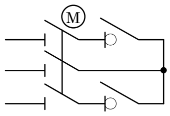
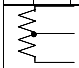
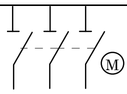
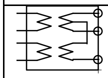
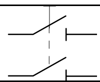
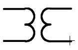
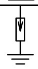
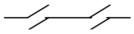
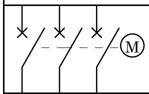
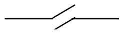
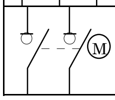
3) Changeover Section System

For neutral section (NS), changeover section system is adopted. In this system, the train is also the regenerative breaking or powering, can pass directly. This system has 50 years of experience in the

Japanese Shinkansen.
The structure of the NS is to be described in detail in 9.10.2(3).

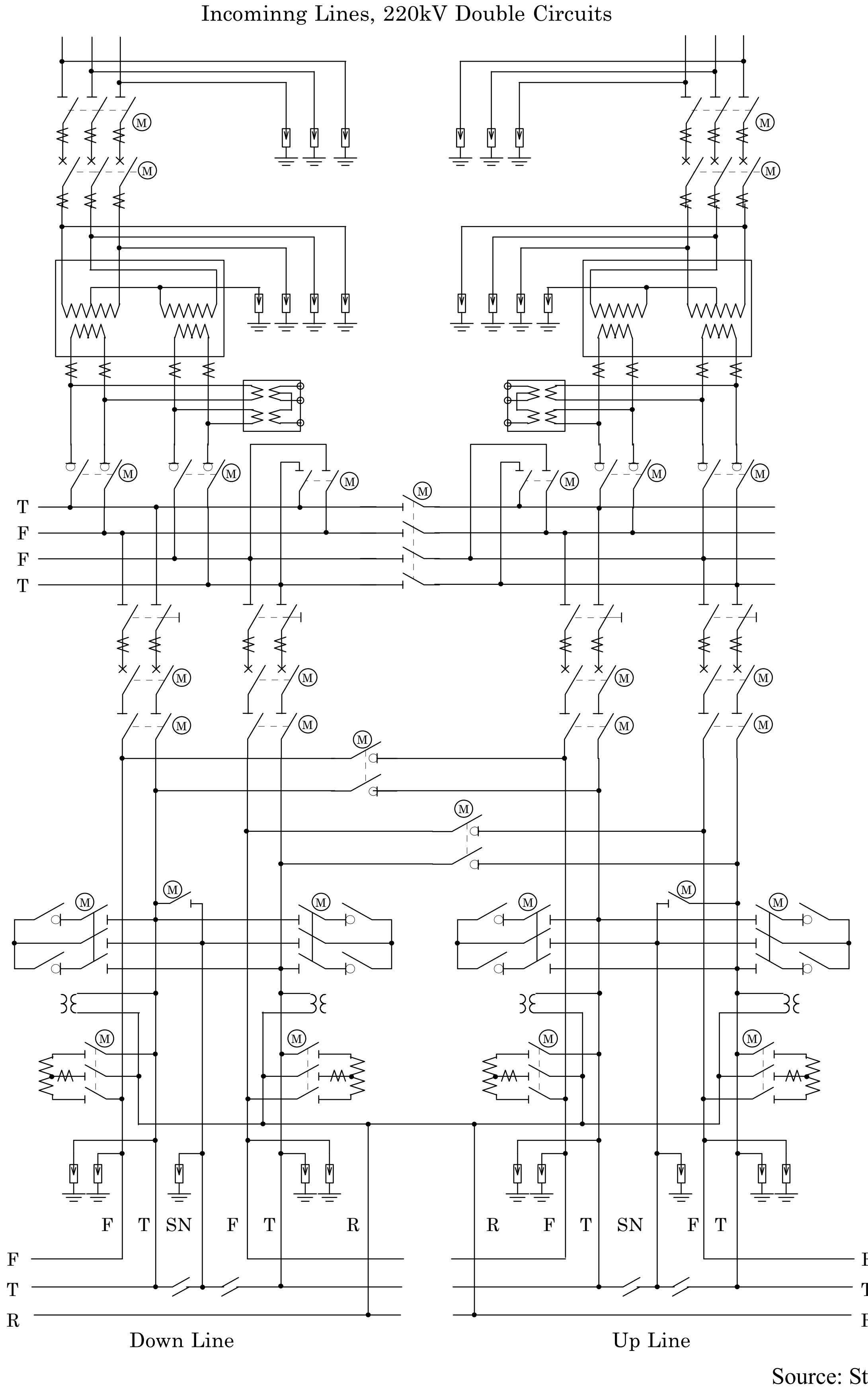
(8) Schematic Diagram of TSS/SP/SSP

The schematic diagram of TSS/SP/SSP is shown in Figures 9.10-18 to 9.10-20 is applied to HSR-1. The name and letter symbol of the schematic diagram is shown in Figure 9.10-17.

Symbol	Name	Symbol	Name
	Scott connected Transformer		Changeover switch
	Auto-transformer (AT)		Isolator (Motor operated)
	LT Supply transformer		Isolator (Manual operated)
	Voltage transformer (VT)		Lightning arrester (LA)
	Current transformer (CT)		Neutral section
	Circuit breaker		Isolated section
	Interrupter		

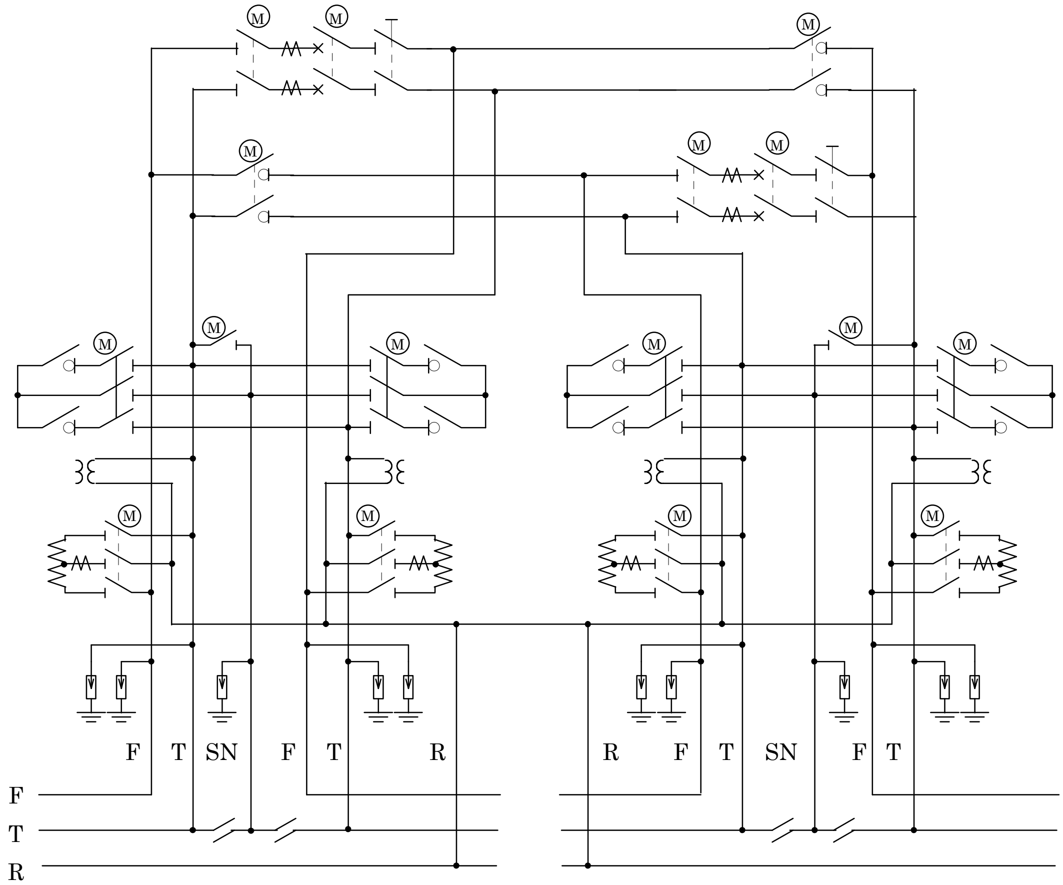
Source: Study team

Figure 9.10-17 Name and Letter Symbol of Schematic Diagram



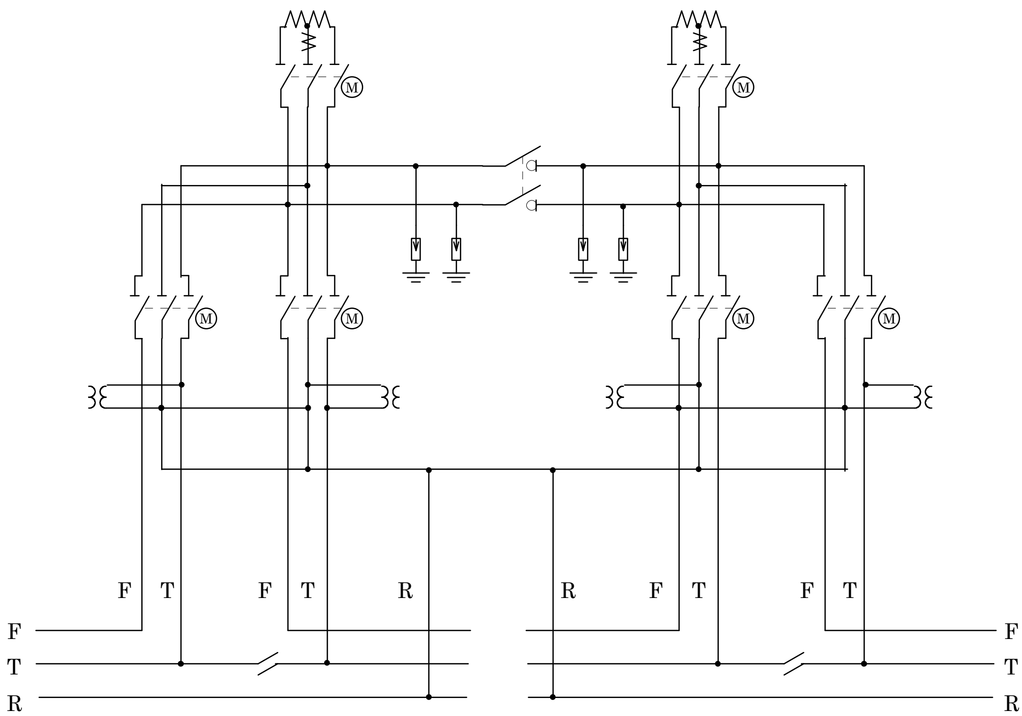
Source: Study team

Figure 9.10-18 Schematic Diagram of Traction Substation (Tentative)



Source: Study team

Figure 9.10-19 Schematic Diagram of Sectioning and Paralleling Post (Tentative)



Source: Study team

Figure 9.10-20 Schematic Diagram of Sub-Sectioning and Paralleling Post (Tentative)

9.10.2 Overhead Equipment (OHE)

(1) Type of Overhead Equipment

The type and characteristics of overhead equipment used for high-speed rails in different countries is shown in Figures 9.10-21 to 9.10-23. The Table 9.10-5 shows the type of OHE used by countries that operate high-speed trains at 300km/h or above. Japan has been using compound catenary and simple catenary as OHE. The compound catenary is used when the traffic volume is high and simple catenary is used when traffic volume is not very high.

The TGV Paris South-East (PSE) of the French Railways (SNCF) line, which was opened in 1981, uses simple catenary system with stitch wire, in order to improve the current collecting performance. However, since the adjustment of the OHE is difficult, SNCF has adopted the simple catenary system in the new lines that was built since then. In addition, the PSE line has also been changed to the simple catenary system in section with speed of 270km/h or more.

The Beijing-Tianjin line in China, which opened in 2008, has also adopted the simple catenary system. However, with the introduction of German technology, the new lines which were opened thereafter, have adopted the simple catenary with stitch wire system.

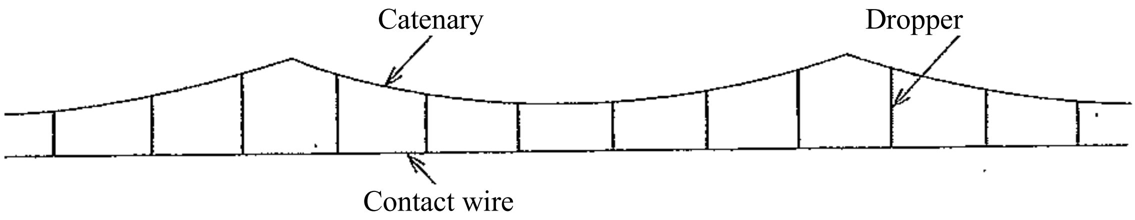


Figure 9.10-21 Simple Catenary System

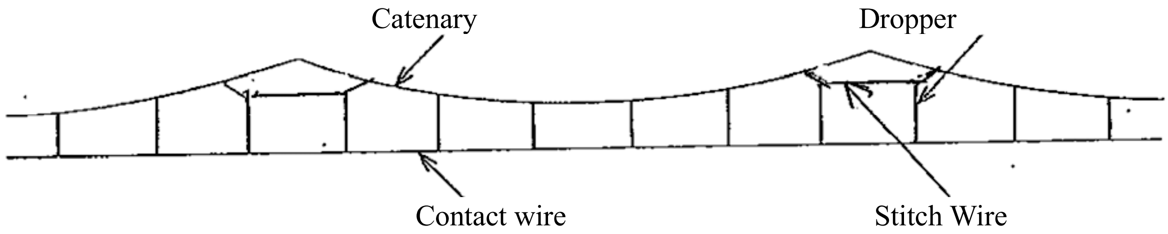
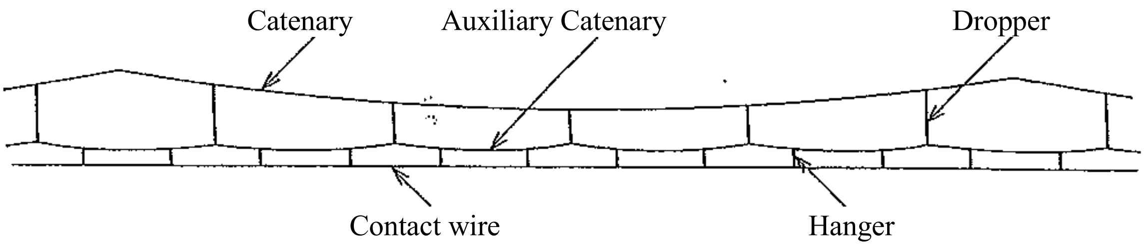


Figure 9.10-22 Simple Catenary with Stitch Wire System



Source: Study team

Figure 9.10-23 Compound Catenary System

Table 9.10-5
Overhead Equipment Adopted in the main Countries which Operate High Speed Rail

Type of Over Head Equipment	Name of Country
Simple Catenary	Japan, France, U.K., Italy, China, South Korea
Simple Catenary with Stitch Wire	France, Spain, Germany, China,
Compound Catenary	Japan, Taiwan

Source: Study team

Table 9.10-6 shows the characteristics of OHE as adopted in different countries. Only Japan and Taiwan are using the compound catenary system whereas other countries use simple catenary system. Since the traffic volume is large in the Japanese Shinkansen, it is necessary to supply large amount of current. The allowable current of compound catenary is 1000A and simple catenary is 800A. The material of the OHE is copper except for the catenary cable, for which it is steel.
The contact wire had used hard copper in Tokaido Shinkansen when it was opened in 1964. At that time maximum speed was 210km/h. The speed of the train becomes 270km/h as the PSE line of France, increased tension of the contact wire. For this reason, it began to use copper alloys such as bronze of high tensile strength. At present, contact wire made of alloy of copper with the addition of 0.1 to 0.5% Magnesium (Mg) or silver (Ag) has also been used in France, Germany, and China.In Japan, the standard span length is 50m, but there are cases of 60m also in the Tokaido Shinkansen. However, considering accident prevention due to heavy winds, span length is kept at 50m. In France, 54m is the standard span, and the maximum is set to 63m. However, in the Mediterranean TGV line, span length is 45m to 50m in areas of heavy winds. In Germany, span is set to 65m if wind speed is low.

Table 9.10-6 Overhead Equipment of High-speed Rail

Name of country	Japan	China	France	Germany
Overhead Equipment	Compound Catenary	Simple catenary with stitch wire	Simple Catenary	Simple catenary with stitch wire
Catenary wire	Galvanizing steel 180mm^2 2 450daN	Bronze 120mm^2 2 100daN	Bronze 116mm^2 2 000daN	Bronze 120mm^2 2 100daN
Auxiliary catenary wire or stitch wire	Hard-Drawn cupper 150mm^2 980daN	Bronze 35mm^2 350daN	None	Bronze 35mm^2 350daN
Contact wire	Bronze 170mm^2 1 960daN	CuMg 150mm^2 3 000daN	Bronze 150mm^2 2 600daN	CuMg 120mm^2 2 700daN
Span length	50m	60m	54m	65m
Maximum operational speed	320km/h	300km/h	320km/h	300km/h
Allowable current	1 000A	-------	800A	----

Source: Study team

(2) Overhead Equipment for HSR-1

1) Natural Environment Conditions

Table 9.10-7 shows the ambient air temperature conditions of India and Japan. Table 9.10-8 also shows the wind speed in Japan. The maximum temperature is 40 degree centigrade in Japan and 50 degree centigrade in India. So it is necessary to take this into account, because it affects the allowable current of OHE. As for wind speed, it should be compared with the situation of winds in the western region of India.

Table 9.10-7 Ambient Air Temperatures (deg. C)

Item	Japan	India
Maximum	40	50
Minimum	-10	-10

Table 9.10-8 Winds Speeds (m/s)

Conditions	Japan
Heavy	50
Normal	40

Source: Study team

2) Arrangement of OHE

Table 9.10-9 shows the arrangement of the general region. Compound catenary is adopted into high density high-speed line due to its high current capacity. In this project its potential traffic volume in the future is estimated to be high, therefore compound catenary should be recommended. However, simple catenary is adopted for sub-main lines and depots. Maximum operation speed on rigid OHE is restricted under 160 km/h, therefore adopting it in tunnels should not be selected and compound catenary should be selected even in tunnels for high speed operation. The arrangement of OHE in tunnel section and disaster prevention region is given in Table 9.10-10 Wire and cable type having excellent heat resistance is adopted in tunnel section and disaster prevention regions.
OHE with a standard span of 50m is proposed. This is because the project section is located in a strong wind area.

Table 9.10-9 Arrangement of OHE (General Region)

Item	Main Line	Sub-Main Line / Depot
Type of Overhead equipment (OHE)	Compound catenary	Simple catenary
Catenary wire	Galvanizing steel 180mm^2 2 450daN	Cadmium copper 65mm^2 980daN
Auxiliary catenary wire	Hard-drawn cupper 150mm^2 980daN	None
Contact wire	Bronze 170mm^2 1 960daN	Hard drawn copper 107mm^2 980daN
Negative Feeder (AT Feeder)	Hard-drawn Aluminum 300mm^2 392daN	None
Standard Span	50m	50m

Source: Study team

Table 9.10-10 Arrangement of OHE (Tunnel Section and Disaster Prevention Region)

Item	Main Line
Type of Overhead equipment (OHE)	Compound catenary
Catenary wire	Galvanizing steel 180mm^2 2 450daN
Auxiliary catenary wire	Silver-containing Hard-drawn copper 150mm^2 980daN
Contact wire	Silver-containing Hard-drawn copper 170mm^2 1 960daN
Negative feeder (AT Feeder)	ACSR 330mm^2 1 470daN (Aluminum Cable Steel Reinforced)

Source: Study team

Table 9.10-11 shows the standard spacing of droppers and hanger on the OHE. Also, Table 9.10-12 shows height and gradient of contact wire.

Table 9.10-11 Standard Spacing of Hanger and Dropper

Item	Hanger	Dropper
Compound catenary	5 m	10 m

Source: Study team

Table 9.10-12 Height and Gradient of Contact Wire

Section	Height of Contact Wire	Gradient
High-speed		Less than 1/1000
Less than 110km/h	5m +/- 0.1m	Less than 3/1000
Depot/Workshop		Less than 5/1000

Source: Study team

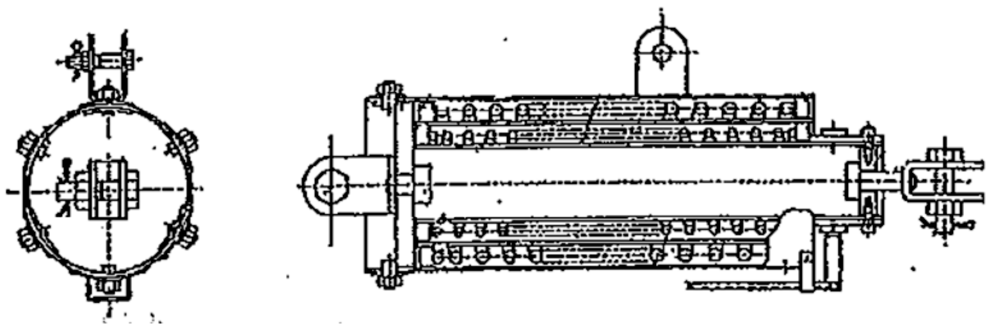
(3) Automatic Tensioning Devices (ATDs)

Automatic tensioning device (ATD's) is used to maintain constant tension automatically and thus maintain good performance for current collection. In Tokaido Shinkansen, since it's opening in 1964, pulley type ATD has been used. The picture is shown in Figure 9.10-24. However, in this method, there is a need to apply oil to the cable that connects the weight and pulley. In addition, wire breakage due to aging of the cable also occurs.
To replace this method, spring tension adjustment "spring type ATD" was developed. The picture is shown in Figure 9.10-25. It is compact as compared to the pulley type. Weight is also lighter than the 1500kg of pulley type.

Figure 9.10-24 Pulley type ATD

Source: Study team

Figure 9.10-25 Spring type ATD



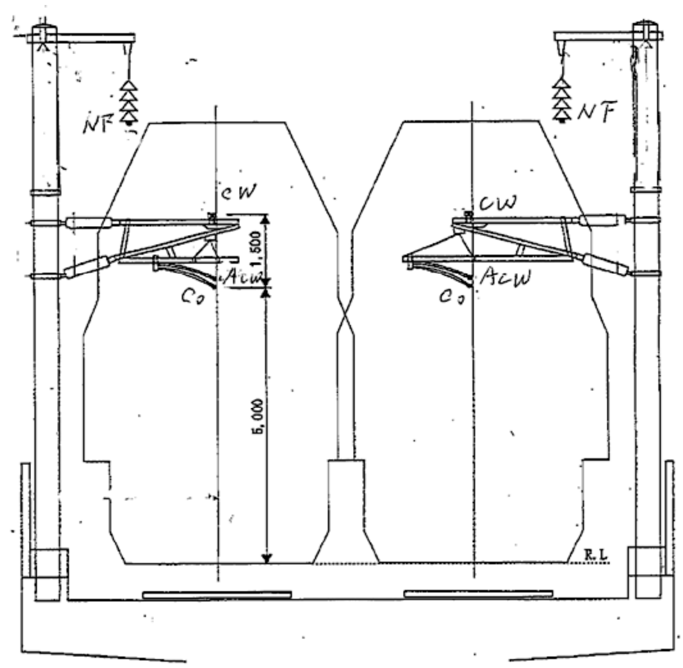
Source: Study team

Figure 9.10-26 Internal Structure of Spring

Figure 9.10-26 shows the internal structure of the spring. The spring has large stroke and is compact due to the two-stage structure of the coil spring.
Currently, conversion from pulley type to spring type is being promoted in Japan's Shinkansen. After confirming weather conditions of the project area, the spring type is proposed for adoption.

(4) Standard Arrangement of OHE

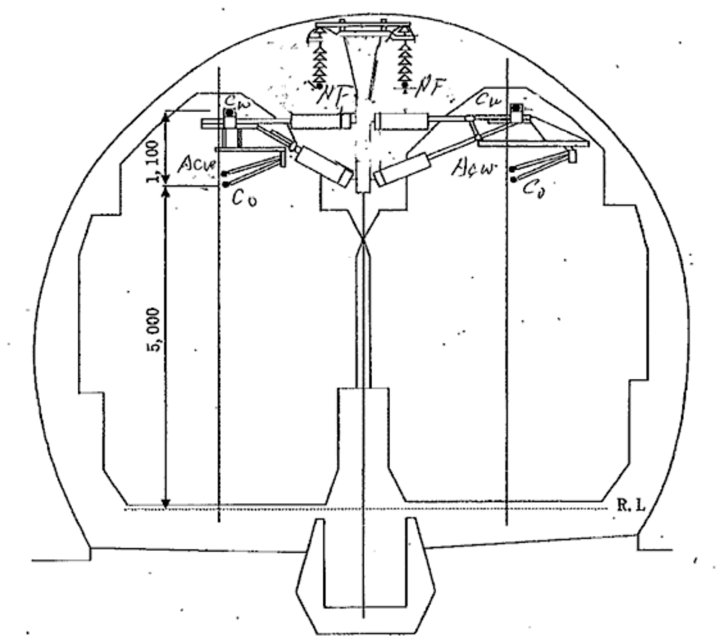
The standard arrangement of OHE for viaduct section is shown in Figure 9.10-27, and for tunnel section, it is shown in Figure 9.10-28. In this arrangement, distance of contact wire (Co) and catenary wire (Cw) at bracket is 1500mm. And, distance of contact wire (Co) and auxiliary wire (Acw) is 150mm. In tunnel section, distance of Cw and Co is 1100mm at bracket. Distance of Co and Acw is same as that for viaduct section



Cw: Catenary wire　Acw: Auxiliary catenary wire　Co: Contact wire
NF: Negative feeder

Source　Study team

Figure 9.10-27 Standard Arrangement of OHE (Viaduct Section)



Cw: Catenary wire　Acw: Auxiliary catenary wire　Co: Contact wire
NF: Negative feeder

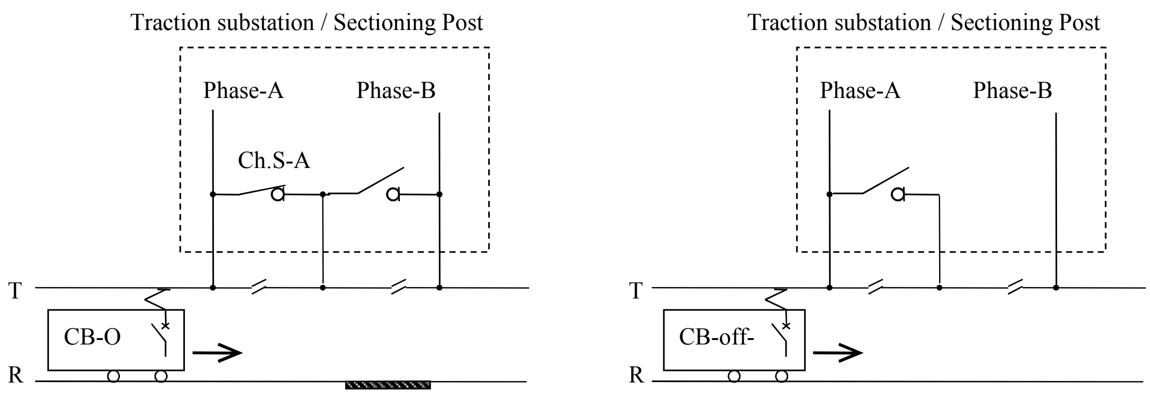
Source　Study team

Figure 9.10-28 Standard Arrangement of OHE (Tunnel Section)

(5) Neutral Section

1) Type of Neutral section

Neutral sections (NS) are of two types. One is power supply installation (PSI) side switching method, and other is on-board circuit breaker (CB) off method. They are show in Figure 9.10-29.



Ch.S : Changeover switch   CB : Circuit breaker   T : Catenary   R : Rails

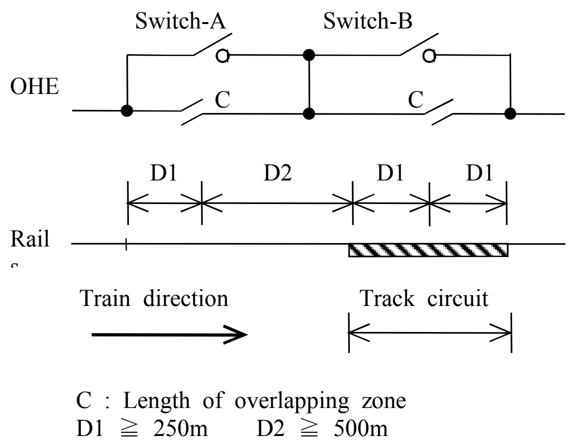
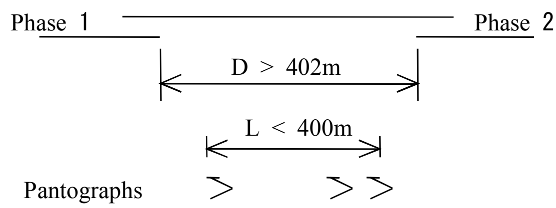
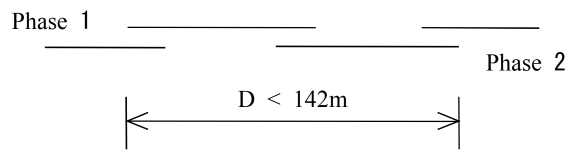
(a) Power Supply Installation side switching Method   (b) On-board CB Off Method

Source: Study team

Figure 9.10-29 Type of Neutral Sections

The PSI side switching method is called “the changeover section system”. In this system, the train is also the regenerative breaking or powering, can pass directly. This system has 50 years of operational experience in the Japanese Shinkansen. In the on-board CB off method, there is “Long neutral section system” (being used the TGV Paris-South-East (PSE) since 1981) and the “Split neutral section system” which has been developed in recent years. The split neutral section system is used LGV Est in France since 2007. Figure 9.10-30 shows type of neutral section.

The changeover section system has been adopted in Japan and Taiwan, and on-board CB off system has been adopted in Korea, France, the U.K., and Italy.

<table>
<tr><th colspan="2">Type</th><th>Configuration</th></tr>
<tr><td>(a)</td><td>Changeover section</td><td>
</td></tr>
<tr><td>(b)</td><td>Long neutral section</td><td>
</td></tr>
<tr><td>(c)</td><td>Split neutral section</td><td>
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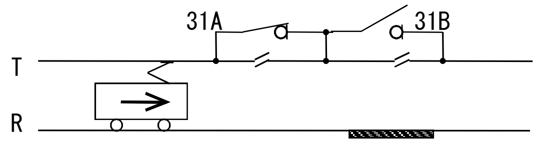
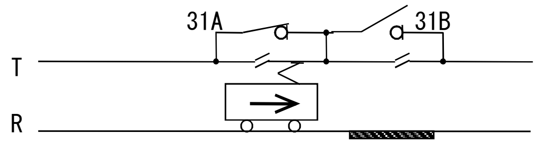
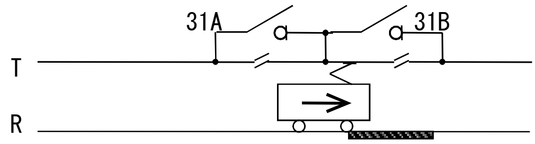
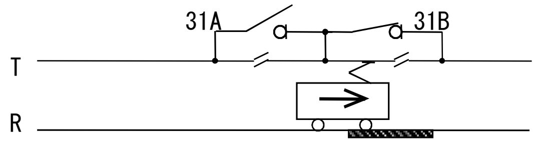
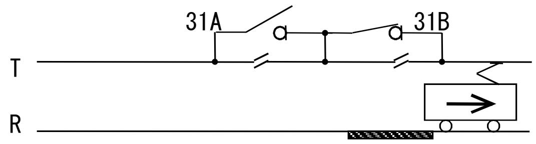
</table>

Source Study team

Figure 9.10-30 Type of Neutral Section(NS)

2) Configuration of the Neutral Sections for the Changeover Section

The changeover section has the configuration as shown in Figure 9.10-31. The main devices are the track circuit, switch-A, switch-B, section-A, and section-B. The figure illustrates the down direction for, switch-A is normally on mode, switch-B is normally off mode. Figure 9.10.2.10 shows the power outage state of the train in the changeover section system. The power outage time is about 0.3 seconds, the running speed of the train is about 27m is power outage mileage in the case of 320km/h.

Item		Operation of the train and switches
(a)	Passing train is before the section-A	
(b)	Train passed the section-A	
(c)	Track circuit detected the train (Switch-A off)	
(d)	On switch-B after switch-A Off	
(e)	Train passed the track circuit	
(f)	Go back the state (a)	

Source　Study team

Figure 9.10-31 Operation of the changeover switches when the train passes the changeover section

Table 9.10-13 shows main specification of the changeover switch. Also, Figure 9.10-32 shows photo of vacuum interrupter type changeover switch. The medium high-voltage load break switch (Interrupter) of general, main circuit opening and closing operation recommended numbers is 10 000 times. However, the changeover switch is guaranteeing the operation of 200 000 times in the mechanical life and 100 000 times in electrical life.

Table 9.10-13
Specifications of Changeover Switch

Item	
Rated Voltage	42kV
Rated Current	1 200A
Rated Frequency	50/60Hz
Rated Closing Current	31.5kA
Rated Short Time Current	12.5kA
Rated Closing Operation Voltage	DC100V
Duty of Operations	O-1sec.-C, C-1sec.-O
Power Frequency Withstand Voltage	
Phase to Earth	70kV, 1 min.
Terminal to Terminal	84kV, 10 min.
Switching impulse withstand voltage	250kV
Capable of Continuance Closing/Opening	
Mechanical	200 000 times
Electrical	100 000 times

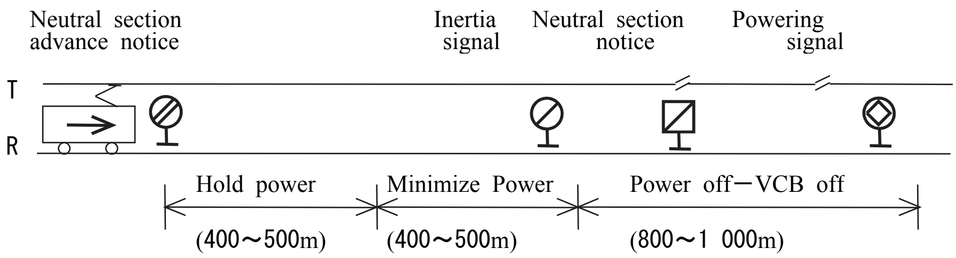
Source: Study Team

Source: Study team

Figure 9.10-32
Vacuum Interrupter type Changeover Switch

3) Configuration of the Neutral Sections for the Long neutral Section

The Korea Train eXpress (KTX) as an example where long neutral section (LNS) system is employed. Figure 9.10-33 shows the LNS passing situation. The coasting distance of the train which is the sum of power off-VCB off time and minimum power length is 1 200m to 1 500m, power off mileage has become 800 to 1 000m. Also, the running speed of the train is converted to time in the case of 320km/h, the coasting time is 13 to 16 seconds, and it is 9 to 11 seconds power off time. Auxiliary equipment such as air conditioning also stops power off during this time.



Source Study team

Figure 9.10-33 Neutral Section Passing Situation in Korea Train eXpress (KTX)

Problems of on-board CB off method

(a) Many problems have occurred due to operational mistakes of motormans.
(b) Speed may drop because the train is coasting in the NS.

For this reason, some countries have developed the changeover section. France carried out tests to install vacuum switch (VS) on the mast, but did not succeed. China and South Korea have also tested thyristor switch system, but have not been successful.

4) Performance results of two neutral sections

Table 9.10-14 shows the evaluation of the PSI side switching method and on-board CB open method.

Table 9.10-14 Performance Results of Two Neutral Sections

Item	PSI side switching Method	On-board CB Off Method
Power Outage time	0.3 sec.	
(at 320km/h)		9 to 11 sec.
(at 160km/h)		18 to 22 sec.
Train Coasting Length		1 200 to 1 500 m
(at 320km/h)	27 m	
(at 160km/h)	14 m	

Source Study team

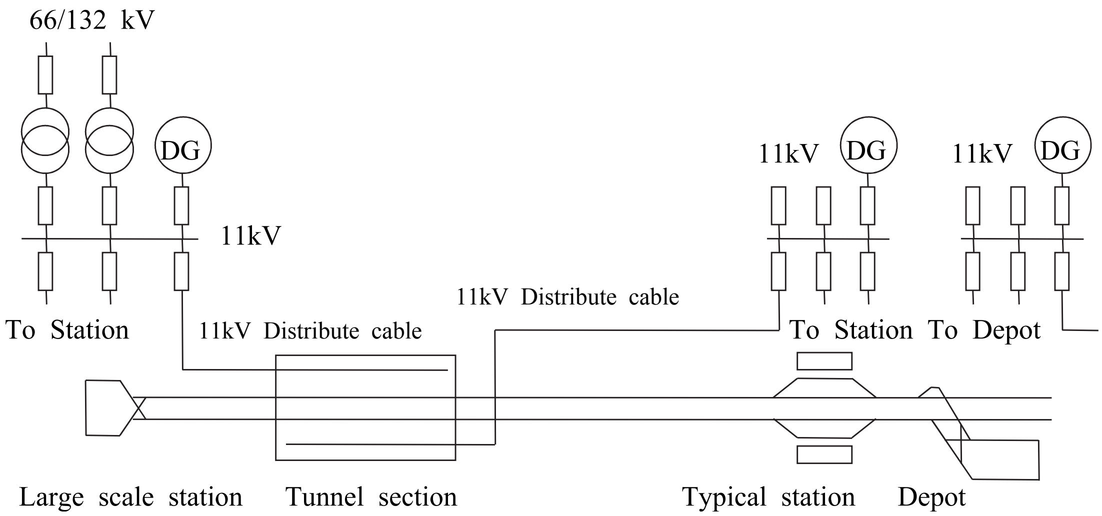
9.10.3 Lights and Electrical Facilities

(1) Overview of Lights and Electrical Facilities

The lights and electrical facilities used in high-speed rail are: (a) distribution facilities for stations, (b) distribution facilities for workshop and depots, (c) distribution cables between stations.

Figure 9.10-34 shows the overview of the distribution cable and high voltage (HV) distribution facilities. The double circuits of incoming 11kV serve as a power source for stations, workshop and depots, and a diesel engine generator (DEG) is also installed as a countermeasure for power outages. However, for large stations such as Mumbai station, an incoming voltage of 66/132kV is used because the power load is large in such stations.

For supplying power to maintenance vehicles, to signals and telecommunication equipment etc. an 11kV power line is installed. This is single circuit, but in order to improve reliability of power supply in long tunnels of 5km or more, double circuits drawn from different directions are installed.



Source Study team

Figure 9.10-34 Overview of the Distribution Circuit and the High-voltage Distribution Equipment

(2) Power Distribution Facilities

Power distribution facilities are required for stations, depots, workshops and for drainage facilities of the Thane creek tunnel. Table 9.10-15 shows incoming plan of distribution facilities for stations and depots.

Table 9.10-15 Incoming Plan of Distribution Facility for Stations and Depots

Station/Depot/Workshop/Drainage post name		Total Length (km)	Incoming Voltage (kV)	Nos. of Circuit (Nos.)
01	Mumbai/station	0.0	66/132	2
02	Thane creek/drainage post	6.9	11	2 (3)
03	Thane/station	27.9	11	2
04	Thane/depot	29.5	11	2
05	Virar/station	64.9	11	2
06	Boisar/station	104.4	11	2
07	Vapi/station	168.9	11	2
08	Bilimora/station	217.2	11	2
09	Surat/station	264.5	11	2
10	Bharuch/station	323.1	11	2
11	Vadodara/station	396.9	11	2
12	Anand/Nadiad/station	447.1	11	2
13	Ahmedabad/station	499.8	11	2
14	Sabarmati/Station	505.2	11	2
15	Sabarmati/Centre	507.0	11	2
16	Sabarmati/Workshop	507.0	66/132	2

Source　Study team

9.11 Signalling/Telecommunications

This section describes the proposed Signalling and Telecommunications (S&T) plan for the Mumbai-Ahmadabad HSR corridor. It gives alternative technological options and recommends the most suitable system for the project.
The present Joint Feasibility Study provides the main design features of the signalling and telecommunications for the operation of the line, as also the associated sub systems like passenger information systems and Facility-SCADA, etc. according to the requirements of the new HSR corridor, taking into account the proven systems of Shinkansen and European systems.

The signalling described for the design of the Mumbai-Ahmadabad HSR corridor are:

- Automatic Train Protection (ATP) system
- Fall-Back Block system
- Interlocking device
- Track Vacancy Detection system
- Electric Point Machine
- Systems to realize “Fail-safe” operation
- Power Supply of signalling
- Cable for signalling, and
- Monitoring for signalling

The telecommunications of the Mumbai-Ahmadabad HSR corridor consists of:

- Digital Train Radio system
- Backbone network using Optical Fiber Cable (OFC)
- Public Address (PA) system
- Closed Circuit Television (CCTV) system
- Passenger Information System (PIS)
- Telephone system
- Clock system
- Facility-SCADA (F-SCADA)
- Power Supply of telecommunications, and
- Cable for telecommunications

9.11.1 Signalling

The Signalling shall provide the highest security level to ensure that the operational activities are developed following strict safety requirements. At the same time it shall meet the requirements for efficient train operations and high quality of service.

(1) ATP system

1) ATP system suitable for HSR

Overlooking a wayside signal may cause a serious accident when high-speed trains with more than 250km/h run. It is necessary to indicate allowable maximum speed on on-board monitor continuously and also to control brake automatically in case of over speed.

As mentioned in Section 4.6.4, ATP systems are categorized as shown in Table 9.11-1.

Table 9.11-1 Categorization of ATP System

functions / Transmission	attentiveness check, train stop function and others, but without brake supervision	with brake supervision, but without dynamic speed profile	dynamic speed profile
intermittent	Group 1	Group 2	Group 4
continuous	Group 3		Group 5

Source: "Railway Signalling & Interlocking", Eurailpress, 2009

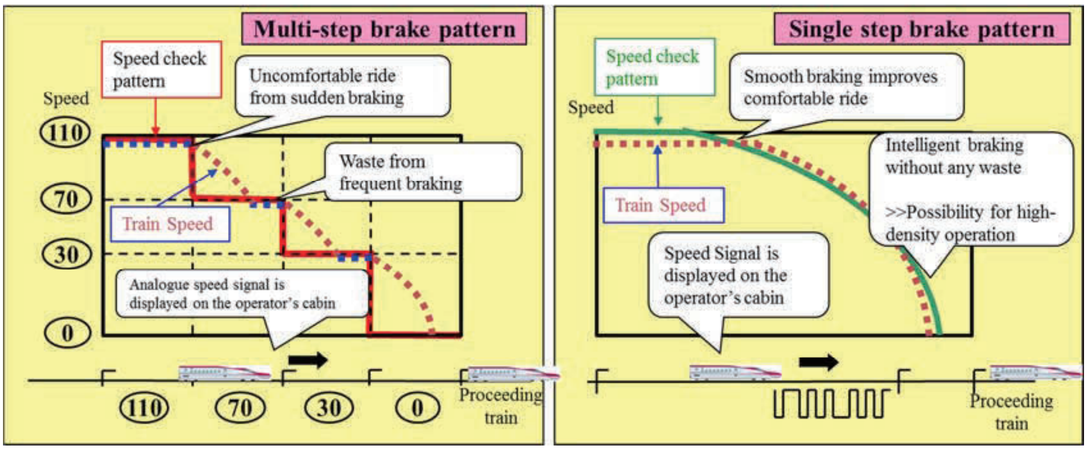
The ATP Systems belonging to "Group 5" meets the requirement for HSR. Some examples of continuous ATC system with dynamic speed profile used on high speed lines in the world are:

- Digital-ATC
- ETCS Level-2
- CTCS Level-3
- TVM-430
- LZB

These have Continuous update of Movement Authority (hereinafter referred to as MA) & Cab Signaling. The Mumbai-Ahmadabad HSR will have state-of-the-art Cab signal and a continuous control with single-step brake supervision.

2) ATP system with Single-step brake pattern and comparison with Multi-steps brake patterns

Cab signal system is essential for HSR over 250km/h because of visibility and continuous brake control system has excellent responsiveness contributing high safety, high speed and high frequency. In continuous brake control type, conventional ATP system having multi-step brake transmits permitted speed information every block to the on-board device via analog signal sent from the ground. On the other hand, single-step brake type makes the ground equipment send MA including stopping point information by digital signal. The on-board device makes or retrieves single-step speed check profile (single-step braking pattern). And the on-board device compares the train speed and the train position with the speed check profile. Recent digital technology makes ATP system sophisticated. This type is better train control because the on-board device can deal with a lot of data. ATP system with single-step brake achieves better riding comfort for passengers and shortened operation headway which leads possibility for high density operation. (Figure 9.11-1)



Source: JR East

Figure 9.11-1 Difference between Multi-step Brake Pattern and Single-step Brake Pattern

3) Recommendation for ATP system of the Mumbai-Ahmedabad HSR Corridor

It is suitable for the Mumbai-Ahmedabad HSR to introduce a proven ATP system having continuous control with single-step brake supervision. Among the single-step brake type used in the world HSR, although there are some systems such as Digital-ATC, ETCS Level-2, TVM430 and LZB, the study team has extracted Digital-ATC and ETCS Level-2 from them because TVM430 and LZB are now being replaced with ETCS Level-2 step by step for interoperability among Europe countries based on the interoperability directive of European Union (EU).
Comparison between Digital-ATC & ETCS Level-2 for featured elements is shown in Table 9.11-2.

Table 9.11-2 Comparison between Digital-ATC and ETCS Level-2

	Digital-ATC	ETCS Level-2
Safety Integrity Level	SIL-4	SIL-4
Block system	Fixed block	Fixed block
Type of signalling	Cab signalling	Cab signalling
Method for track occupancy detection	Track circuit (AFTC (Audio Frequency Track Circuit))	Track circuit (AFTC) or axle counter, etc.
Transmission method of MA	Rail	GSM-R
Braking Pattern	Retrieval of single-step braking pattern	Calculation by on-board device
Deceleration Control	Smooth automatic braking when trains stop at stations	Automatic braking when trains stop at stations
Running distance when train stops	As same as ETCS L-2	As same as Digital-ATC
Line Capacity on new constructed project	As same as ETCS L-2	As same as Digital-ATC
New installation	A few number of equipment -ATC & Interlocking device -Track Circuit -Fixed balises	-Radio Block Centre (RBC) -GSM-R network (MSC and BTS, etc.) -Interlocking -Device for track occupancy detection -Fixed balises
In operation as of 2013	2,182km	2,281km
Comparison of cost	As same as ETCS L-2	As same as Digital-ATC

Source: Study Team

Digital-ATC should be recommended as ATP system of the Mumbai-Ahmadabad HSR due to the following reasons:

- Japan Shinkansen HSR with Digital-ATC has no fatality for 50 years.
- Digital-ATC has less equipment than ETCS Level-2, which reduces maintenance cost.
- Digital-ATC has higher safety, availability and reliability.
    - Digital-ATC Hazard Rate: order of 1 x 10^{-11} [1/hour] (ETCS: 0.67 x 10^{-9} [1/hour])
    - Digital-ATC Design Specification of Availability: 99.998% (ETCS: 99.985%)
    - In Digital-ATC, all of the devices and networks in equipment room have redundancy configuration.
    - On Digital-ATC number of functional failure of signalling equipment during 2002-2013 is one in JR-East Shinkansen.

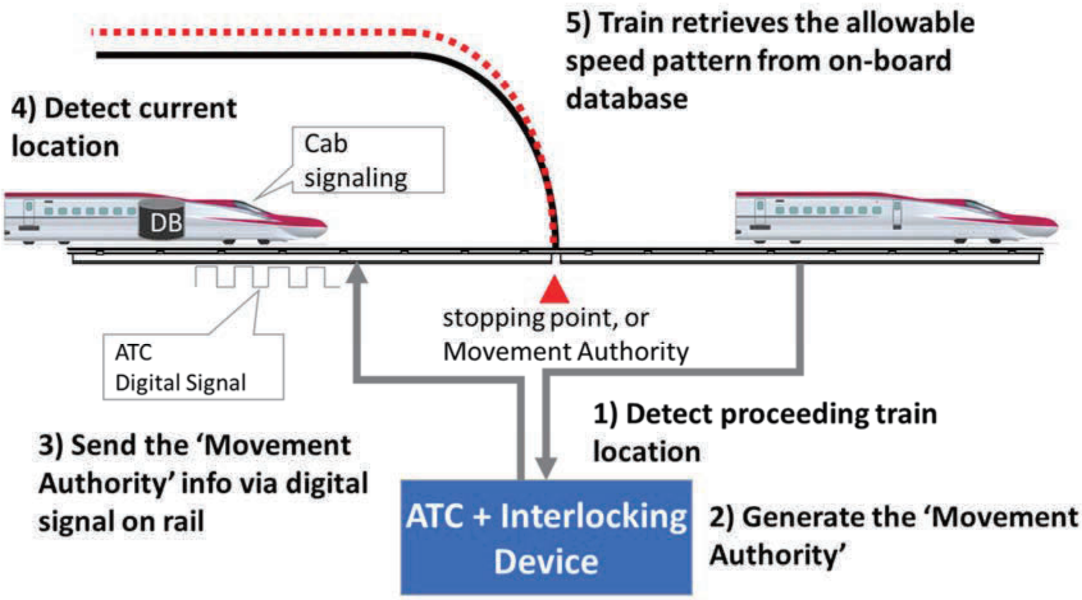
    Although fall-back system with Digital-ATC is not essential, fall-back system can be provided using train radio system and axle counter if Indian Railways wants.
- Digital-ATC has brake pattern stored on high-speed trains, so response time is fast.
- With Digital-ATC, OCC dispatchers can directly send command to high-speed trains when temporarily needed.
- Cost of Digital-ATC and ETCS Level-2 is approximately same.
- ETCS Level-2 seems to be suitable in case of upgrading ETCS Level-1 section because equipment like track circuit can be re-utilized.
- In ETCS Level-2, GSM-R network is necessary to be installed as a sub-system of ETCS Level-2. However, Indian Railways GSM-R frequency band allotted is now only 1.6MHz (952.8-954.4/907.8-909.4MHz), which is not sufficient to control high-speed trains.
- In ETCS Level-2, GSM-R capability to support full requirements of ERTMS is limited, as a result new technological solutions, namely GPRS, are being tried for providing quasi-simultaneous communication with large numbers of trains in densely traffic areas.

4) Digital-ATC System

a) Overview

In Digital ATC system, MA is sent to on-board device of high-speed train via rail from signal equipment room. The on-board device retrieves single-step brake pattern based on the profiles such as running resistance, gradient and speed limits for turnouts and curves from the MA and the location of the train. If the train exceeds the speed indicated by the signal, the speed will be reduced automatically. By having optimal brake control according to individual train functions, the Digital-ATC system can minimize braking loss, shorten the scheduling time, and enhance riding comfort.

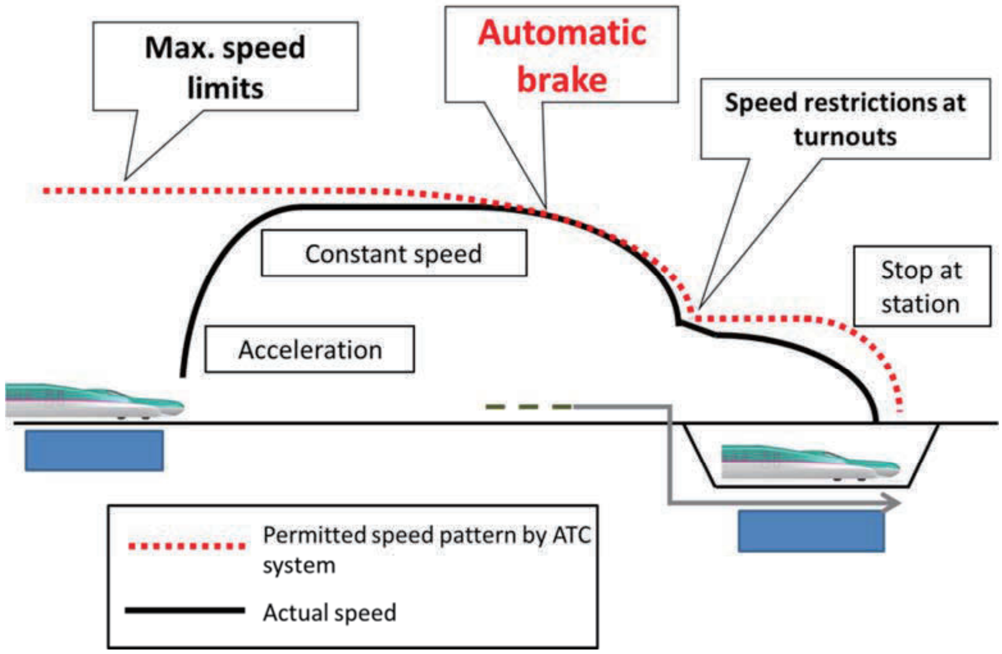
Figure 9.11-2 shows the flow of brake pattern generated by Digital-ATC.



Source: JR East

Figure 9.11-2 The Flow of Brake Pattern Generated by Digital-ATC

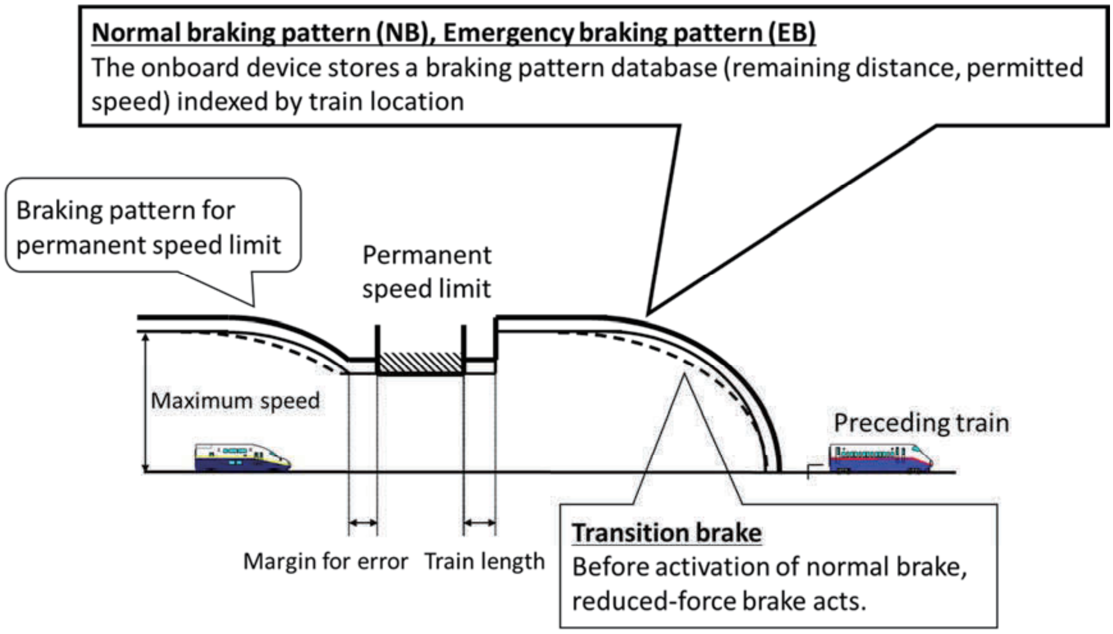
Digital-ATC has automatic deceleration up to 75km/h which is consideration of restriction speed of turnout in stations from the operation speed when train stops at stations as shown in Figure 9.11-3.



Source: JR East

Figure 9.11-3 Acceleration and Deceleration of Digital-ATC

As written above, the on-board device stores the profile on geographic condition and permanent speed limit like turnouts and curves in advance. On the other hand, as for temporary speed limit, OCC dispatchers can directly send command to high-speed trains based on alarms of Disaster Detection and Warning System for rain, water level, wind, and rail temperature. They select the limited speed level and command to the train with assignment of the train number. The on-board system also has transition brake function. This is low-power brake which works before the train speed exceeds the normal brake pattern. Passengers don't feel shock and can have more comfort trip. (Figure 9.11-4)



Source: JR East

Figure 9.11-4 Brake Pattern of Digital-ATC

b) System function

i) System function

- Stop control for stop point
- Speed control for speed limit point (regular speed control, temporary speed limit for work-site, etc.)
- Cab signal aspect and other information indication

ii) Ground equipment functions

➢ Train detection

Judges a track circuit occupied making with a reception level of ATC telegraphic messages and validity of them

➢ Preparation of track circuit information on which train should stop

Decides a stop track circuit for each movement according to information of the track circuit, route configuration and train protection

➢ Preparation of information for temporary speed limit

When a speed limit for work-site is set, prepares information of the temporary speed limit corresponding to the work site and speed.

- ATC telegraphic message transmission

  Edits its own track circuit number, stop track circuit number, speed limit for work-site information and others, adds CRC (Cyclic Redundancy Check, bits for error transmission detection) and a sequential number, and sends them to the track circuit. If the ground equipment detects train stop information, it sends an emergency stop signal to a relevant track circuit.

iii) On-board equipment functions

- Position recognition

  The on-board equipment recognizes a position of the train where it is installed according to signal from a tachometer generator continuously. Also, it corrects its train position according to position information from transponders (balises) installed on the ground.

- Speed check patterns (unique function of Digital-ATC)

  The on-board equipment has speed check patterns for all track circuits that may be a stop point in advance. The speed check patterns include a service brake pattern (NB pattern) and an emergency brake pattern (EB pattern).

- Speed check

  The on-board equipment searches a speed check pattern according to information received from rails such as a track circuit number on which train should stop (unique function of Digital-ATC). It compares the speed indicated by the speed check pattern and the speed of its own train, and controls braking.

- Temporary speed limit

  The on-board equipment searches a speed check pattern for a temporary speed limit according to information of the speed limit for work-site received from rails. It compares the speed indicated by the speed check pattern and the speed of its own train, and controls braking.

- Speed indication

  The on-board equipment indicates speed on a speed meter device of the cab.

- Others

  The on-board equipment indicates a pattern allowable speed and a goal on the speed meter device of the cab.

iv) Speed check patterns

Speed check patterns are given to each pair of remaining distance to a stop track circuit end and a pattern allowable speed at that point. A speed check pattern end (the point of which pattern allowable speed is 0 km/h) is a point with a margin for an error of its own train position from the track circuit end. Speed check patterns include the following estimated items.

- Set deceleration of each train type
- Fluctuation of electric brake and mechanical brake
- Running resistance of each train type
- Brake distance margin
- Gradient
- Regular speed limit such as of turnout and curve

The speed check patterns have the following types:

- Emergency brake pattern (EB pattern): Installed in the equipment in advance
- Service brake pattern (NB pattern): Installed in the equipment in advance
- Transition brake pattern : Calculated in each case according to normal speed check pattern

c) System specification

Safety Integrity Level of Digital-ATC system goes far beyond SIL 4 and all of the devices and networks of the system in equipment room has redundancy configuration to achieve tolerance in failure. Redundant configuration of devices and networks enables high reliability.
Digital-ATC can be combined with Electronic Interlocking System, which is multifunctional in small footprint. Carrier wave of Digital-ATC uses MSK (Minimum-Shift Keying) modulation and continuously transmits to on-board device via rail. Carrier frequencies of ATC wave are decided in consideration of harmonics occurred by traction power system using 50Hz. Example of frequency band applied on HSR is shown in Table 9.11-3.

Table 9.11-3 Frequency of ATC Signal Applied on HSR

Item		Frequency	Remarks
ATC wave (Hz)	Southbound	1,000-1,500 band	ATC signal will be used both on section of track circuit with insulated joints (in stations) and that of non-insulated track circuit (between stations). ATC signal and track circuit with insulated joints will be same wave in stations. ATC signal and non-insulated track circuit frequency between the stations will be different.
	Northbound	1,500-2,000 band	

Source: Study Team

Table 9.11-4 shows other basic specifications of Digital-ATC.

Table 9.11-4 Other Specifications of Digital-ATC Applied in the HSR

Telegram length	58 bit (Frame length: 75 bit)
Telegram sending cycle	1,350 m sec

Source: Study Team

d) System configuration

i) Interlocking ATC integrated logic part

Equipment with interlocking logic and ATC logic: In addition to the interlocking logic, it prepares information of a stop track circuit and a temporary speed limit, and sends ATC telegraphic messages. It has a triple modular configuration (fail-sale configuration by 2 out of 3).

ii) Transmission control part

This part receives ATC telegraphic messages from the interlocking ATC integrated logic part, disassembles and sends them to each transmitter-receiver device. It receives a track circuit reception level and telegraphic message content from each transmitter-receiver, and decides track circuit occupancy. It has a triple modular configuration (fail-sale configuration by 2 out of 3).

iii) Transmitter-receiver

It responds to each track circuit one-by-one, converts ATC telegraphic messages with MSK modulation, and sends them to each track circuit. Also, it demodulates signals from the track circuits and sends them along with levels to track circuit ground system. It has a double modular configuration.

iv) Integrated monitor

It records status of signals transmitting on track circuits, contents of telegraphic messages, and status of electric point machines

v) Gateway

It transmits necessary information with a neighboring ground equipment.

5) Conclusion

Digital-ATC has higher level of Safety, Availability and Reliability, fully meeting with the operational requirements of the Mumbai-Ahmadabad HSR corridor.

(2) Fall-Back Block system

As already mentioned above, Fall Back system for Digital-ATC is not essential because Digital-ATC has a high reliability and availability. But, if Indian Railways desire a Fall-Back Block system, it can be provided on the Mumbai-Ahmedabad HSR corridor, using axle counters and train radio system.

In case equipment for Digital-ATC fails and becomes unavailable, the Fall-Back Block system can temporarily be worked to maintain safety and smooth operation. When the Fall-Back Block system is operated, it is necessary to check no other trains exist in the protection area to keep safety operation at first. To detect trains between stations, axle counter device will be adopted instead of Audio Frequency Track Circuit (hereinafter referred to as AFTC) in Fall-Back mode as shown in Figure 9.11-5. The axle counter system has function to count a number of trains, to transmit data between equipment rooms, and to monitor the data such as log data on counting and voltage.

Source: JR East

Figure 9.11-5 Axle Counter Device as Fall-Back System

In the Fall-Back Block system, the MA is transmitted to the on-board device by Leaky Coaxial Cable (LCX)/radio system based on train detection data by axle counter device. LCX will be laid along the HSR line as shown in Figure 9.11-6. And, LCX will also be used as a transmission method of digital train radio system. Ground signals will be used for block control.

Source: JR East

Figure 9.11-6 LCX Installation Example

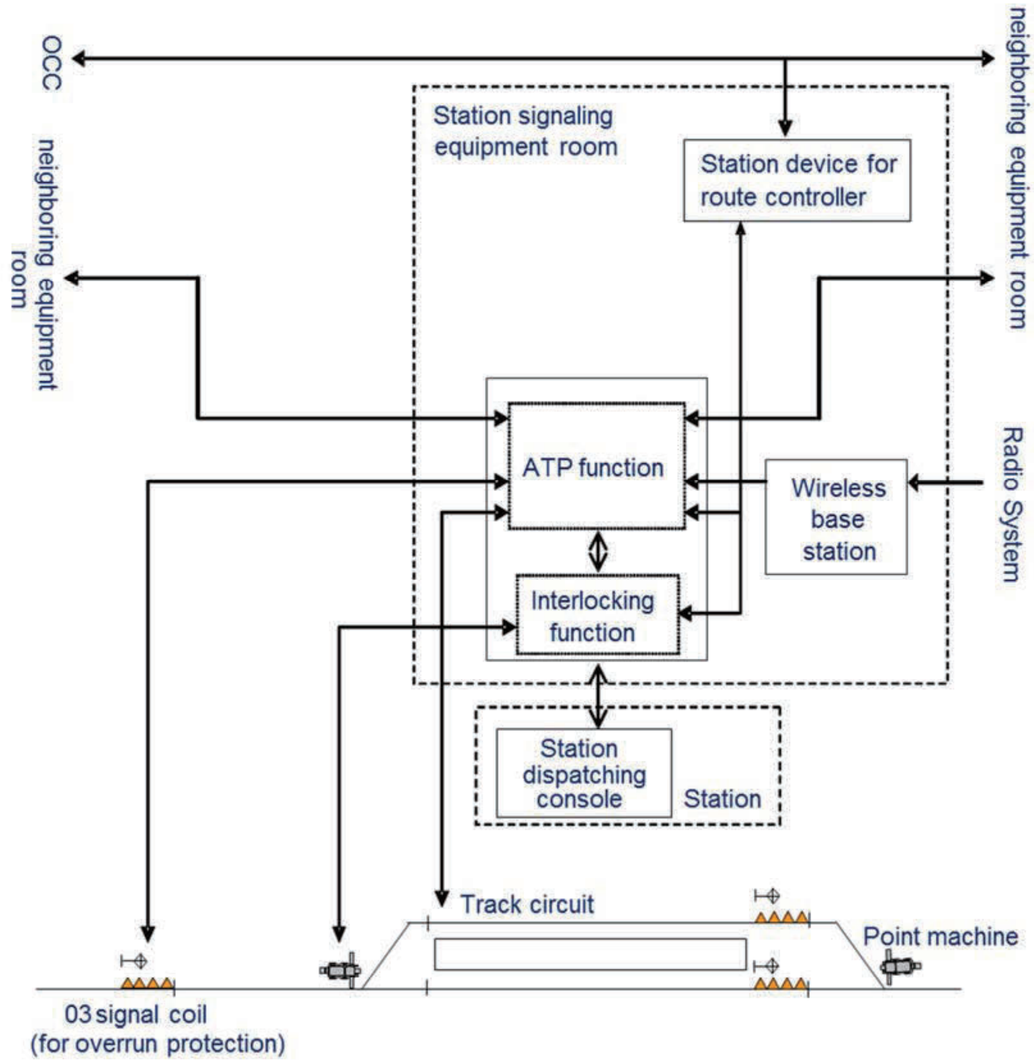
(3) Interlocking Device

Interlocking device normally controls equipment such as track circuits and point machines, etc. and safely makes routes for movement of the trains. In HSR system, the Electronic Interlocking (hereinafter referred to as EI) shall be recommended due to sophisticated data transmission and reduction of a number of devices as well as enhancement of safety. At first, comparison between the EI used in Digital-ATC and that of ETCS Level-2 is shown below.

1) Comparison between the case of Digital-ATC and that of ETCS Level-2

- In case of Digital-ATC

In Digital ATC, a type which integrates Digital-ATC with EI can be introduced. This integrated system can share logical processing unit, power supply unit, and so on. The EI with Integrated Digital-ATC will be with SIL 4 with redundancy devices.
Figure 9.11-7 shows overview of signalling configuration with the EI function integrated with ATP function of Digital-ATC in stations.



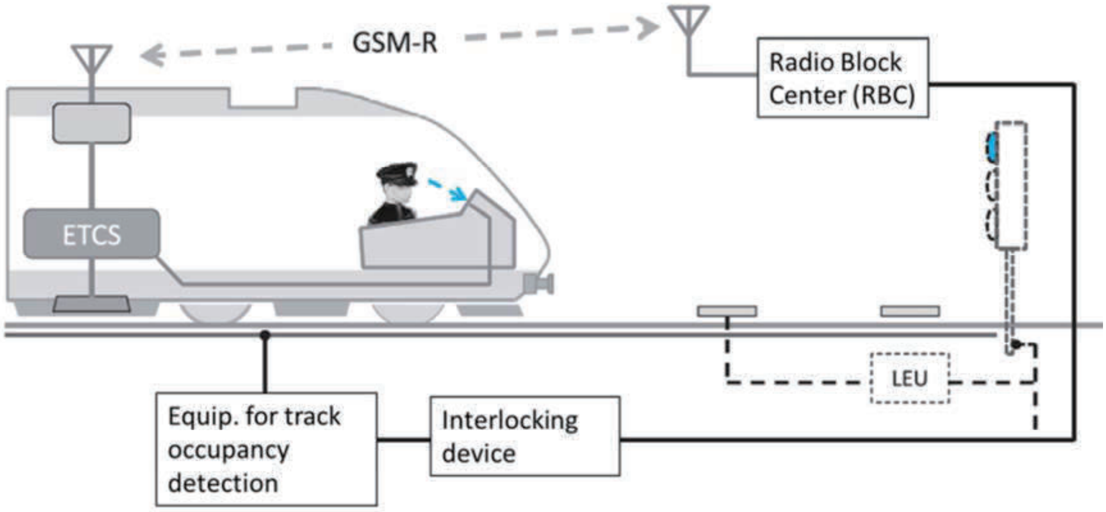
Source: JR East

Figure 9.11-7 Overview of Signalling Configuration at Stations

Site equipment like track circuit and electric point machines shall directly be controlled by IC unit mounted in interlocking system using surge protective devices. And the system shall automatically make train routes based on train diagram and route data stored in a station controller for route controller. Daily train diagram and route data are periodically transmitted before the operation day from operation control system in OCC via telecommunication network.

- In case of ETCS Level-2

On the other hand, ETCS Level-2 has an EI which is different from ATP system. The EI reports the status of objects controlling the routes of the train to the Radio Block Centre (hereinafter referred to as RBC) which in turn generates the correct MA for the different trains in the section. The interface between the EI and RBC has not been commonly specified resulting in adoption of project specific solutions. (Figure 9.11-8)



Source: Edited by Study Team based on ERTMS material

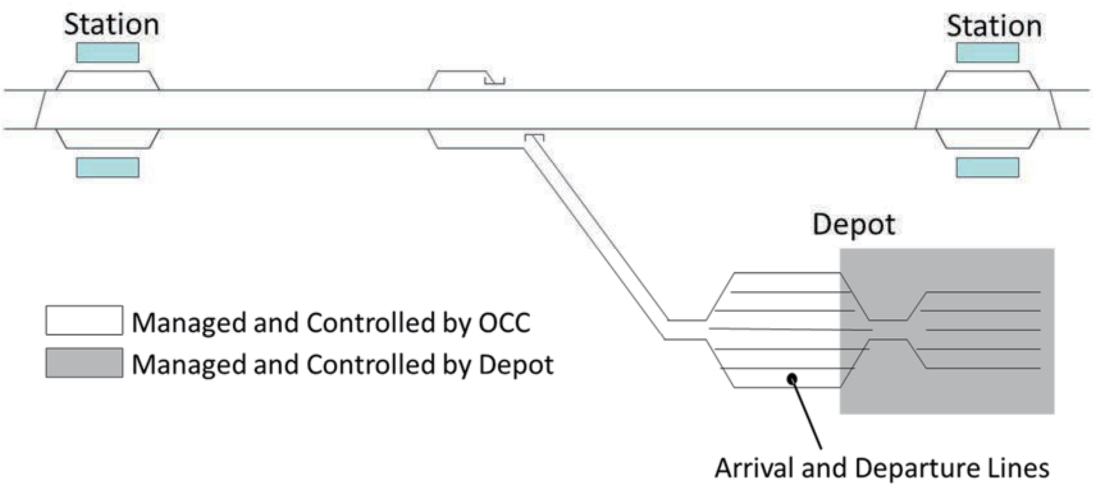
Figure 9.11-8 Interface between Interlocking and RBC on ETCS Level-2

2) Conclusion

On the Mumbai-Ahmadabad HSR corridor, it should be recommended EI of a type which integrates Digital-ATC with EI. The EI integrated with Digital-ATC has been used on Shinkansen HSR, which has lesser equipment and is more reliable, has SIL 4 Safety Integrity Level and has been successfully working for 9 years. The same is recommended for the Mumbai-Ahmedabad HSR.

3) Shunting control and management in depot

Area that OCC supervises high speed trains should be up to arrival and departure lines in depot. In depot, dedicated interlocking system should be installed and signal controllers of depot sets route control for shunting. (Figure 9.11-9)



Source: Edited by Study Team based on JR East material

Figure 9.11-9 Shunting Control and Management in Depot

(4) Track Vacancy Detection system

1) AFTC for the HSR

The use of audio frequencies permits the physical limits of an individual track circuit to be defined by tuned electric short-circuits between the rails rather than by insulation in the rails. AFTC system basically consists of following modules:

- Transmitter
- Receiver
- Tuned Unit (TU)
- Power Supply Unit (PSU)
- Surge arrester-Protections against lightning
- Leads/Connections and fastening to rails

2) AFTC should be on the Mumbai-Ahmedabad HSR corridor

In HSR systems in the world, AFTC is normally used. AFTC is the most proven and safest train detection device for HSR in the world. AFTC is also suitable for HSR system due to easily making non-insulated track circuit and having strong tolerance for power traction system.
In the Mumbai-Ahmedabad HSR with the maximum speed of 320km/h, track circuit is strongly recommended as a device for track vacancy detection, not axle counter device. That is why track circuits fail-safe device and can be used to easily detect rail breakage in long distance section.

3) Recommended Track Vacancy Detection system

- AFTC

The AFTC used in Digital-ATC recommended as ATP system shall be recommended for the Mumbai-Ahmedabad HSR. Example of frequencies for the AFTC applied in main line of the HSR is shown in Table 9.11-5. The frequency of the AFTC is decided in consideration of harmonics using 50Hz in the HSR, and adjacent track circuits use different carrier frequencies. The signal level adjustment function of the AFTC device automatically changes the boarder of occupancy track or vacant. Moreover, capacitors are installed between rails to improve transmission loss. So it is basically unnecessary for maintenance staffs to adjust the level of the AFTC. In stations, the AFTC with insulated rail will be used to make a boundary between track circuits clear.

Table 9.11-5 Frequency of Track Circuit Device Applied in the HSR Main Line

<table>
<tr><td colspan="2">Item</td><td>Frequency</td><td>Remarks</td></tr>
<tr><td rowspan="2">Track circuit in stations (Hz)</td><td>Southbound</td><td>1,000-1,500 band</td><td rowspan="2">Used for train detection on section of track circuit with insulated joints (in stations)
The same signal as ATC signal</td></tr>
<tr><td>Northbound</td><td>1,500-2,000 band</td></tr>
<tr><td rowspan="2">Track circuit between stations (Hz)</td><td>Southbound</td><td>1,500-2,000 band</td><td rowspan="2">Used for train detection on non-insulated track circuit (between stations)</td></tr>
<tr><td>Northbound</td><td>2,000-2,500 band</td></tr>
</table>

Source: Study Team

Carrier wave of the track circuit device uses MSK (Minimum-Shift Keying) modulation as well as ATC signal. Standard track circuit length will be approx.1km to 1.2km. AFTC functions without any problems in section with the leakage conductance about 1.0 S/km. And, the use in submarine tunnel section with much leakage conductance (Max. 3.0 S/km is supposed) is proved as shown in Figure 9.11-10. The HSR shall install capacitors between rails every some intervals and shall not make grounding with rail to stably work. AFTC will mainly be used in main line. In depot, another track circuit will be used except for AFTC area.

Source: JR East

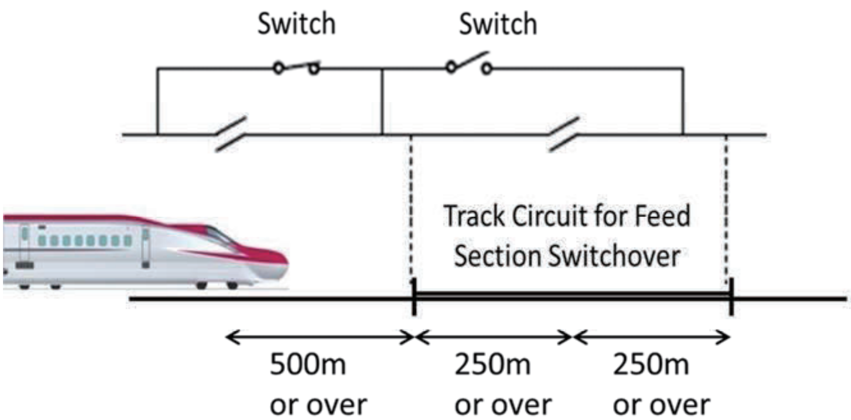
Figure 9.11-10 AFTC to Work in Much Leakage Conductance Section

- 03 signal coil for overrun protection

03 signal coil is a kind of track circuit which composed of cable installing along rails and the length is 50m. These circuit will be in front of next block section boundary because the device will transmit to the train with less than 5km/h of the speed that on-board tachometer generator may recognize error and prevent passing over dangerous boundary.

- Track circuit for section with changeover switch

To make it possible for trains to accelerate on feeding section at substations and sectioning post, the HSR will have section with changeover switch. Dedicated track circuits will be installed due to trigger for switches. Figure 9.11-11 shows track circuit for section with changeover switch.



Source: Study Team

Figure 9.11-11 Track Circuit for Section with Changeover Switch

(5) Electric Point Machine

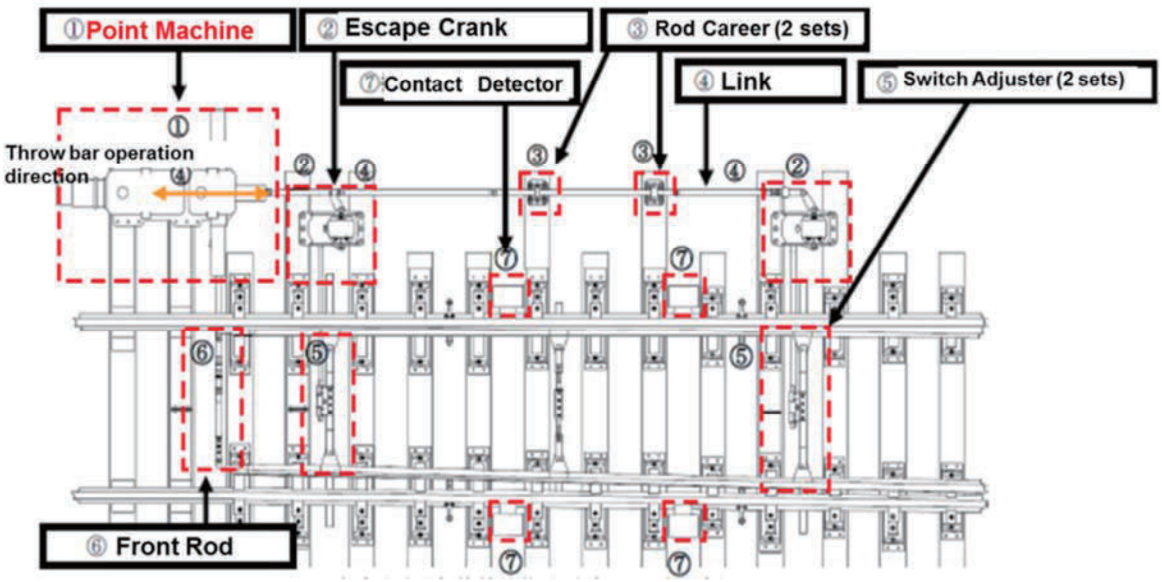
Although various point machines are used in railways, electric point machines are mainly used in HSR sections in the world. The Mumbai-Ahmedabad HSR shall have proven electric point machines for a long time due to highly important equipment in operation with maximum 320km/h, especially in main line. The point machine shall be high power and reliable, that is, to provide connected rail with strong force, to endure strong vibration and have robust lock function.

1) Recommended electric point machine

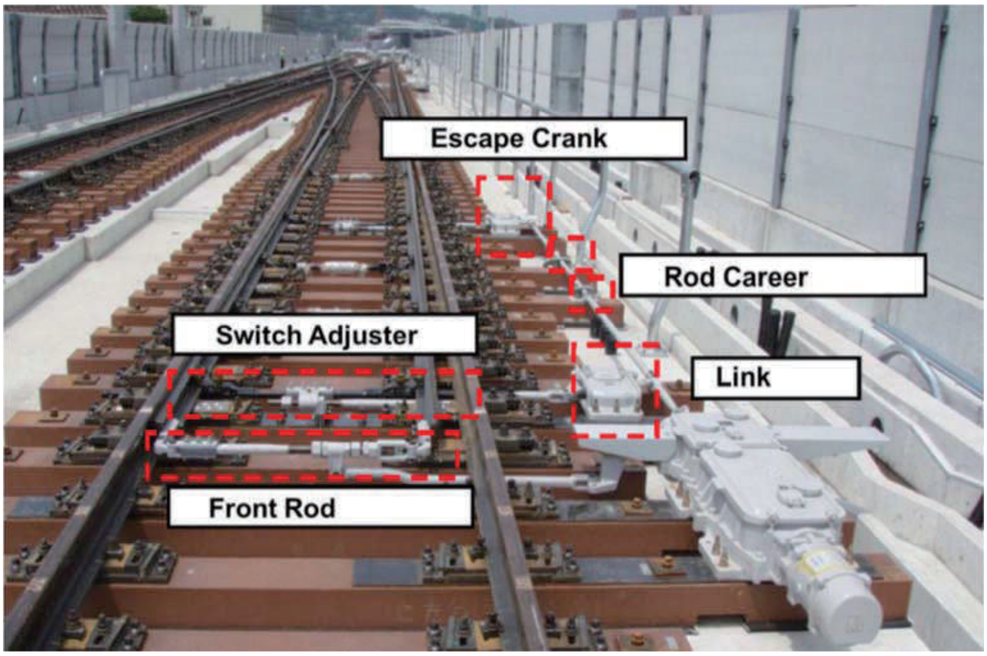
a) Overview

Electric point machine introduced in the Mumbai- Ahmedabad HSR shall be HSR-proven electric point machine compatible with interlocking device. Point machine recommended in the Mumbai-Ahmedabad HSR is stated below.

Switches to control motor in electric point machine shall be installed in equipment room due to preventing dangerous wrong switching by accident of grounding fault, vibration and lightning, etc. At standard turnout in main line, 2 point machines shall be used. Figure 9.11-12 and Figure 9.11-13 shows how to install point machines at tongue rail part and swing nose part in main line of the HSR, respectively. The length of control of point machine for tongue rail part is about 10m. The length of control of point machine for nose part is about 4.5m.

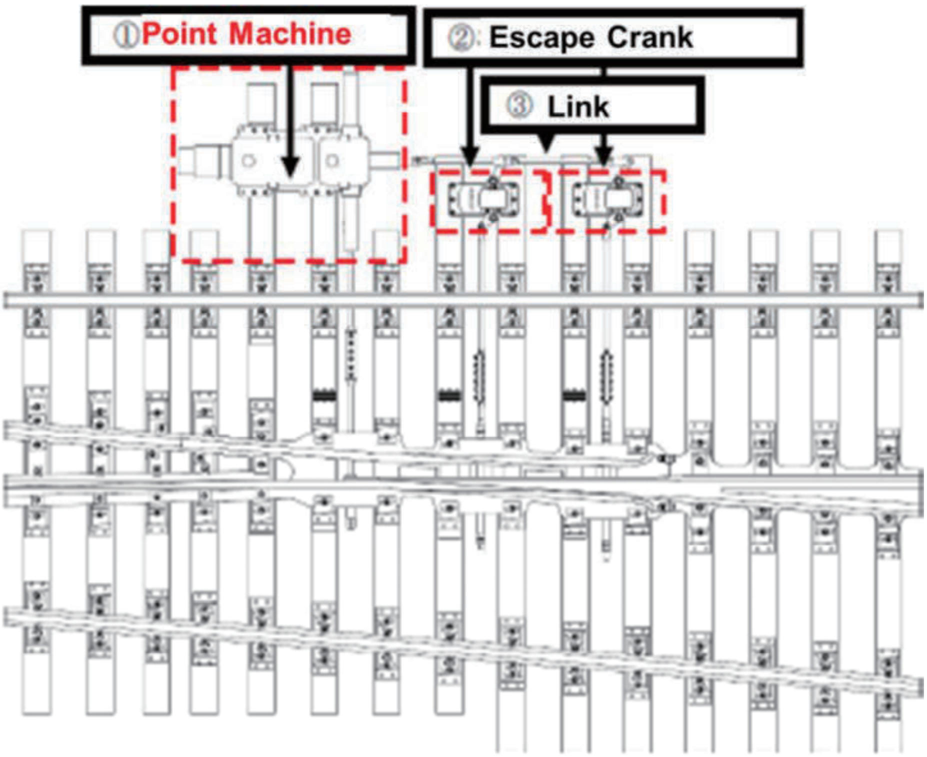


Source: Kyosan Electric Mfg. Co., Ltd

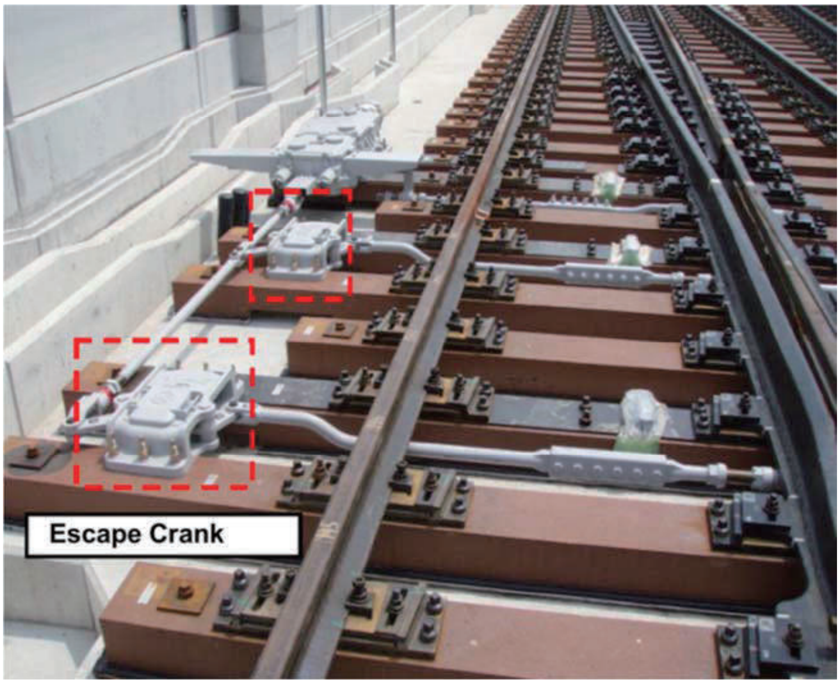


Source: Kyosan Electric Mfg. Co., Ltd

Figure 9.11-12　Electric Point Machine at Tongue Rail Part in Main Line



Source: Kyosan Electric Mfg. Co., Ltd



Source: Kyosan Electric Mfg. Co., Ltd

Figure 9.11-13 Electric Point Machine at Swing Nose Part in Main Line

As for electric point machines in depot, a type used in conventional line shall be accepted because train speed is slow.

b) System specification of the point machine used in main line

Table 9.11-6 shows specification example of the electric point machine recommended in main line for the Mumbai-Ahmedabad HSR. And, Table 9.11-7 shows a number of the electric point machines in main line.

Table 9.11-6 Basic Specification of the Electric Point Machine Recommended in Main Line

Motor	Tolerance for vibration		Stroke (mm)		Max. Load (kN)	Switching Time (sec)
	Frequency (Hz)	Acceleration (m/s^2)	Moving Rod	Lock Rod		
AC Single Phase	500-1000	About 190	200	85-190	About 10	less than 10sec

Source: Study Team

Table 9.11-7 A number of the Electric Point Machines in Main Line

Turnout	Limited speed for reverse side	Number of motors at tongue rail part	Number of motors at swing nose part	Remarks
1:18 (length: 71m)	80 km/h	1	1	Standard turnout

Source: Study Team

c) System configuration of the point machine used in main line

i) Motor

A capacitor activated type induction motor, symmetric two phases 6-pole single phase, with a sealed ball bearing

ii) Gear

A three-stage deceleration mechanism consisting of one pair of bevel gear, and two pairs of spur gear: To reduce abrasion loss of the bearing part, a final switching gear has a cylindrical roller bearing, and the other gears have sealed ball bearings.

iii) Friction clutch

After completion of switching, to prevent impact to the mechanism during rotation and stop of the motor, an hydraulic oil sealing, non-adjustable torque type friction clutch is installed between the large bevel gear at the first-stage and the small spur gear at the second stage, and absorbs the inertia and protects the motor in case of over-load or partway interference.

iv) Switch and lock movement

It is driven by the switching rod roller. A lock piece is driven when the switching roller is moving on the escape surface of the switching rod, and locks the lock rod and the switching rod. Traveling of the lock piece is 50 mm, and mutual interval with the lock rod notch is 1.5 mm.

v) Circuit controller

It is an insertion type three-position controller with mutual interlocking of the lock piece. The circuit controller lever is moved by 10 mm in the left and the right by the crank attached at the bottom frame, and releases a motor contact point and closes a display contact point after the electric point machine completes switching and locking. When switching operation is going on (in other words, unlocking), it closes the motor contact point and a display circuit shorting contact point, and opens the display contact point.

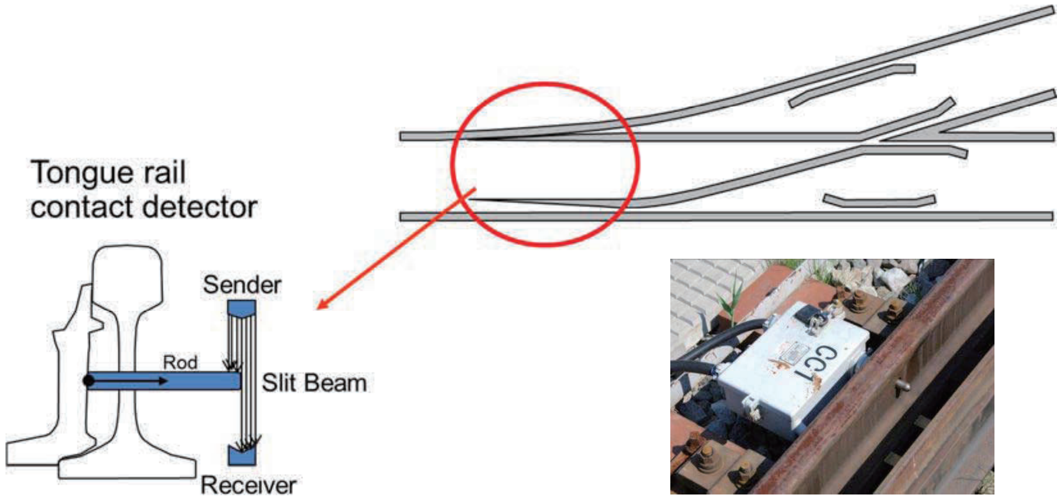
vi) Measuring terminal board

Terminals for measuring display circuit voltage and motor circuit voltage are prepared.

vii) Manual device

When an operator opens a small lid at the motor side on the external box top and fits the safety switch lever to the handle insertion hole, the motor circuit is blocked off and the operator can manually switch with an attached manual handle. In this case, when the operator completes manual switching and locking, a white arrow pointing the switching direction is displayed in the small lid window at the switching rod side on the external box top. When switching operation is going on and the lock is released, the circuit control driving crank interlocks and the white arrow is not displayed.

Furthermore, to prevent serious accident like derailment, the HSR shall have “tongue rail contact detector” to check whether tongue rail and basic rail closely contacts. The device shall be checked by optical sensor which is no problem to function in rainfall and dust. (Figure 9.11-14) The information will be sent to station EI.



Source: Kyosan Electric Mfg. Co., Ltd

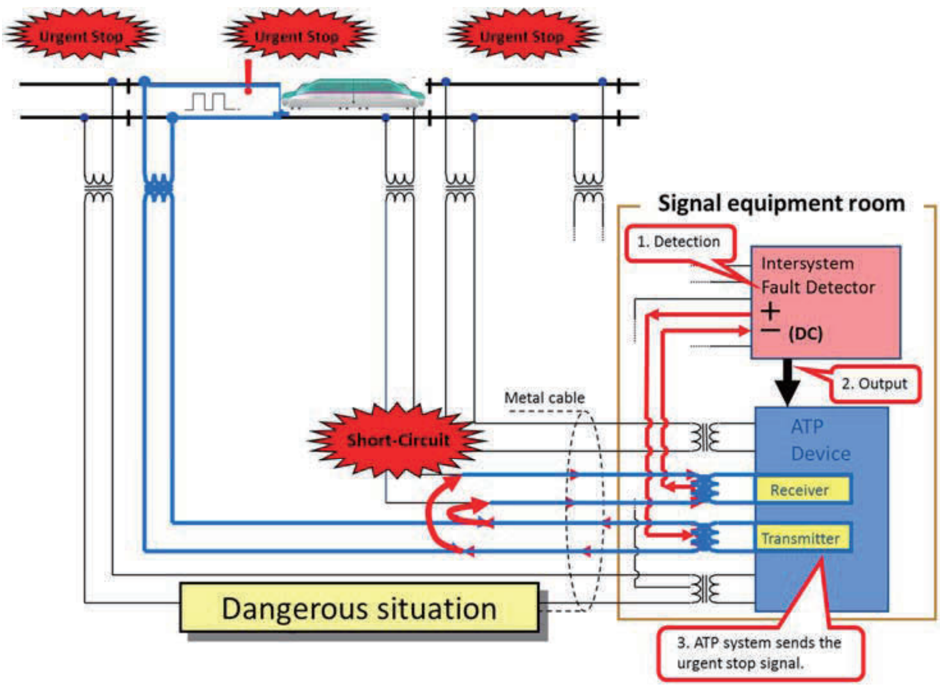
Figure 9.11-14 Installation of Tongue Rail Contact Detector

(6) Systems to realize "Fail-safe" operation

The Mumbai-Ahmedabad HSR corridor shall have various systems and functions to realize "Fail-safe" operation based on Shinkansen experience. The some systems has been introduced in shown below.

1) System to detect intersystem fault

This system has a function to transmit emergency stop signal in case of occurring intersystem fault in the same signal cable. The procedure shows in Figure 9.11-15.

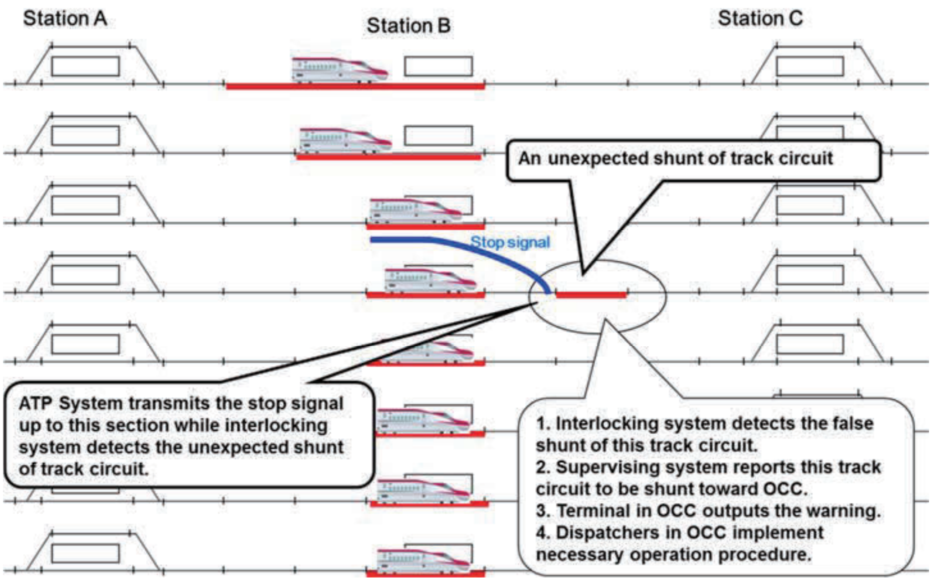


Source: JR East

Figure 9.11-15 The System to Detect Intersystem Fault

2) Function of Interlocking device to prevent collision between high speed trains

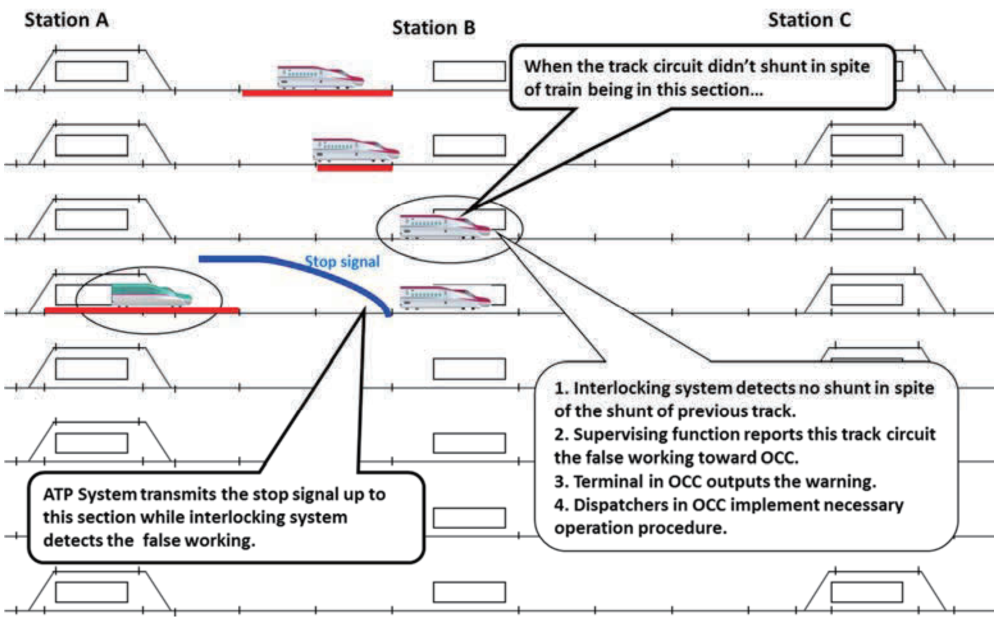
Interlocking device always monitors movement of trains in block order. However, if an unexpected circuit shunt occurred, ATP system would transmit stop signal while interlocking detects unexpected shunt as shown in Figure 9.11-16.



Source: JR East

Figure 9.11-16 Function to Prevent Collision in Case of Unexpected Circuit Shunt

Similarly, in case track circuit doesn't shunt in spite of train being in a section, ATP system transmits the stop signal up to the section while interlocking detects the false working as shown in Figure 9.11-17.

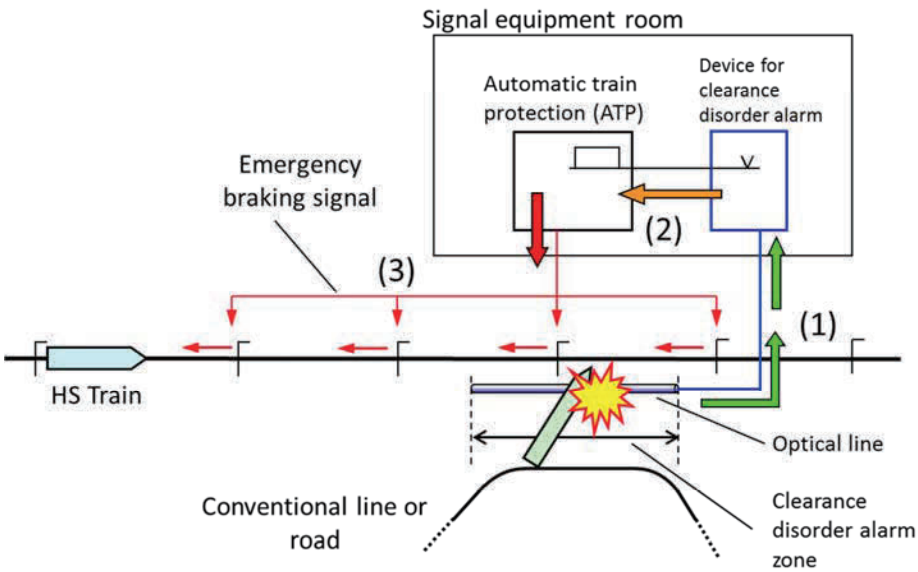


Source: JR East

Figure 9.11-17 Function to Prevent Collision in Case of No Occurrence of Circuit Shunt

3) System to prevent collision with conventional trains or cars

This system would stop related high speed trains if conventional trains parallel with HSR or cars running on nearby roads derailed. Optical cable is laid on fences and walls at the boundaries between HSR and conventional lines or roads. If conventional trains or cars overturn over the boundaries, the trains or the cars is supposed to make these cables cut off. Therefore the system realizes an emergency situation and sends the signal for emergency stop automatically. (Figure 9.11-18)



Source: JR East

Figure 9.11-18 System to Prevent Collision with Conventional Trains or Cars

(7) Power Supply of signalling

Power for signalling will be supplied from each station and intermediate equipment room. Power from overhead equipment will also be used as an auxiliary power. Regular power will be redundant loop configuration. On power receiving, insulated transformers will be installed in each receiving power point. Power supply devices consist of power distribution boards, insulation transformers with box housing, Uninterruptible Power Supply (UPS), rectifiers and batteries.

(8) Cable for signalling

Signal equipment installed in signal equipment rooms will connect with wayside equipment via cables along the HSR line. Cables are basically laid in the duct which will be installed by civil construction work. In tunnel sections, cables are installed at wall of tunnels.

(9) Monitoring for signalling

Almost of signal equipment shall be monitored at OCC and maintenance centers installed in each station, etc. for finding equipment breakdown and preventing failure in advance, using Facility-SCADA. Dispatchers in OCC will check and supervise these data so that they can precisely instruct maintenance staffs to repair failure equipment and control train operations.

9.11.2 Telecommunications

Almost of telecommunications can utilize the same system as that of conventional line. However, digital train radio system and backbone network should be considered for safe and reliable operation of HSR.

(1) Digital Train Radio System

1) Digital Train Radio System suitable for the HSR

The Mumbai-Ahmedabad HSR shall introduce train radio system with digital transmission as stated in Section 4.6.4.

Comparison between digital train radio systems used in world HSR systems is shown in Table 9.11-8.

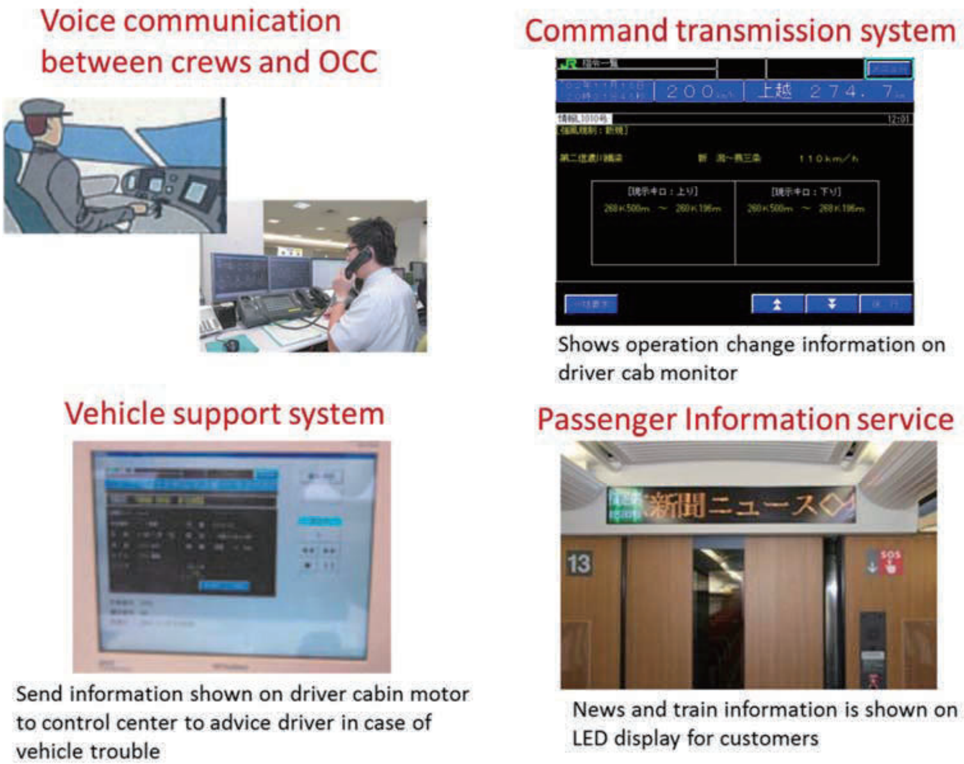
Table 9.11-8 Comparison between Digital Train Radio Systems

	Dedicated Type	GSM-R	TETRA
Type of radio transmission	LCX	Space radio	Space radio
Modulation type	π/4 DQPSK	GMSK	π/4 DQPSK
Voice quality	High	Normal	Normal
Data rate	691.2kbps (high)	270.8kbps (middle)	36kbps (low)
Channel bandwidth	518kHz	200kHz	25kHz
Typical cell size	Along a railway line	5 to 10km	10 to 25km
Comparison of cost	✓	✓✓	✓✓
Special applications for HSR	- Command transmission - Vehicle support - Passenger info. - Fall back system to Digital-ATC	- Command transmission	- Command transmission
Remarks	Combination with Space Radio in some area is possible	Installation of LCX is required in long tunnel and place where it is difficult for radio waves to penetrate.	Installation of LCX is required in long tunnel and place where it is difficult for radio waves to penetrate.

Source: Study Team

Study team recommends the dedicated system using LCX which has high voice quality and data rate. This type will have applications like passenger information and command transmission as shown in figure 9.11-19, and this can also be used as fall-back system to Digital-ATC if Indian Railways want.

The system consists of central control device, control station device, base station device, repeater, and LCX cables. There is a dedicated maintenance system which can monitor, control, measure each equipment from OCC and maintenance centers.



Source: JR East

Figure 9.11-19 Applications of the Dedicated Train Radio System using LCX

The system function, basic specification and configuration are shown below. Details of GSM-R and TETRA are excluded from this report because Indian Railways had already introduced their systems.

2) System function of the dedicated Digital Train Radio System

There are two major functions of the dedicated type, a voice system and a data system.

a) Voice function

i) Telephone function for traffic control

Telephone system for communication between a train dispatcher and drivers

ii) Telephone function for passenger services

Telephone system for passenger services between a dispatcher and train conductors

iii) Communication line for service and public

Telephone system for communication between train crews and industrial civil service organizations

iv) Operation broadcasting information

Broadcasting of train dispatchers to drivers

v) Conductor broadcasting information

Broadcasting of dispatchers for passenger services to conductors (dispatchers for conductors only)

b) Data transmission function

i) Traffic control notice

Data of dispatchers for crews from train dispatchers are transmitted and displayed on the on-board monitor.

ii) Traffic control

MA is transmitted via LCX cable as fall-back system of Digital-ATC, if necessary.

iii) Passenger information

Data of train delays, transfer to conventional lines and other information for passengers on-board from dispatchers for passenger services are transmitted and displayed on the on-board LED indicator.

iv) Monitoring train radio equipment

Troubles and operation state of the on-board radio equipment are transmitted to dispatchers in OCC.

v) Vehicle technology support

Data of train operation state, vehicle equipment state, and other related information which the vehicle monitor monitors are transmitted to train dispatchers in OCC.

3) System specification of the dedicated Digital Train Radio System

The dedicated train radio system uses the Time Division Multiple Access (TDMA) system for their digital train radio communication and generates multiple channels with their unique sound CODEC called "RL-CELP," which is a suitable voice coding system for the train radio communication in HSR.
Table 9.11-9 shows basic specifications of train radio system used in the Mumbai-Ahmedabad HSR.

Table 9.11-9 Specifications of Train Radio System Used in the Mumbai-Ahmedabad HSR

Basic specification	Access system	(Base station transmission) Time Division Multiplexing system (Mobile station transmission) Time Division Multiple Access system
	Modulation	(Base station transmission) π/4DQPSK (Mobile station transmission) π/4DQPSK
	Frequency	(Base station transmission) 900 MHz band, 1-wave (Mobile station transmission) 900 MHz band, 1-wave
	Transmission output	(Base station transmission) 2 W (Mobile station transmission) 4 W
Quality	Service area	Available for 99.99% or more in all sections
	Bit error rate	1×10^{-4} or lower
	Voice	Voice coding system RL-CELP (Very high-clear voice) Transmission speed 5.6 kbps
	Data	Data rate Approx. 700kbps

Source: Study Team

4) System configuration of the dedicated Digital Train Radio System

The overall radio zone is divided into each base station, which is the minimum unit for the train radio, for the radio line control. When dispatchers call a train crew member from OCC, they specify a train number, or specify an area where the relevant train exists and calls it by voice. The area specified by the director who uses the voice call system is called "call zone" (of which minimum unit is a radio zone). Since the area is defined in consideration of the operation system of directors, the call zone for the telephone system for traffic control has a different size from that of the call zone for the telephone system for dispatcher for passenger services.

a) Central apparatus

i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station

ii) Connection of the control operation desk and other equipment with the train radio system

iii) Monitoring terminals are set up at the OCC and they can supervise on-board equipment installed in high speed trains in real time.

b) Control station device

i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station
ii) Voice line and data line control for the communication line for service and public between the control station and the mobile station
iii) Tracking control of voice line
iv) Connection of telephone system

When a call is continuing even when a train enters into the neighbor zone, the control station device tracks that call so that the communication is maintained in the neighbor zone. For that purpose, it is necessary to reserve a common channel in surrounding zones in advance and to disable that channel in other trains.

c) Base station device

i) Transmission and reception of electric waves with the mobile station devices
ii) Conversion between radio signals and signals for wire communication

d) Relay device

i) Amplifier to compensate LCX transmission loss

e) LCX

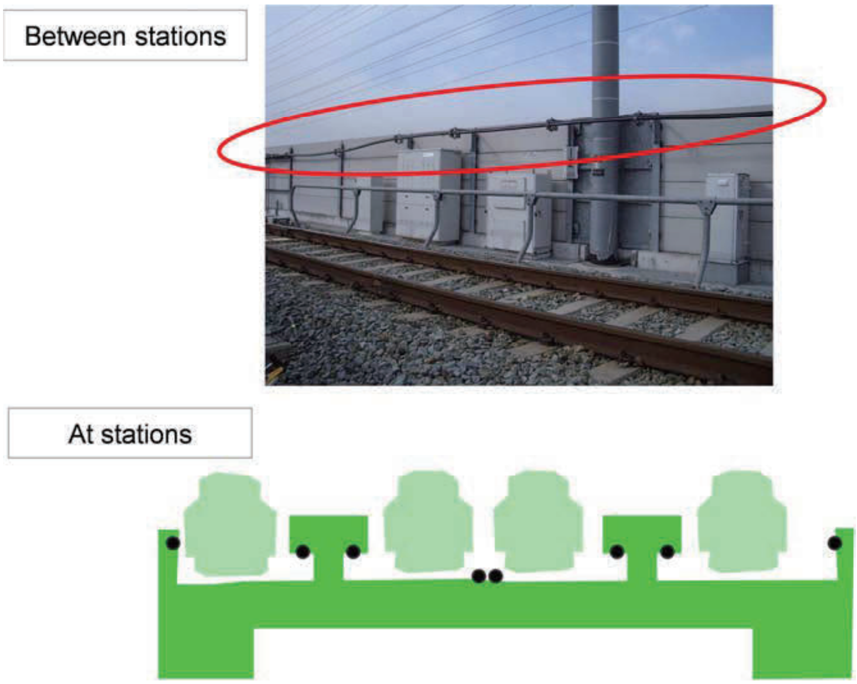
i) Propagation and radiation of electric waves sent from the base station
ii) Reception and propagation of electric waves sent from the mobile station
iii) Transmission of the relay device power

f) Mobile station device (on-board)

i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station
ii) Voice line and data line control for the communication line for service and public between the control station and the mobile station

iii) Connection of the operating panel and other on-board equipment with the train radio system

As shown in Figure 9.11-20, LCX cables shall be installed at both sides of the HSR line.



Source: JR East

Figure 9.11-20 LCX Layout along HSR Line

(2) Backbone network using OFC

1) OFC system

An OFC system to give end to end communication connection between distant places and to provide connectivity through every site locations along the section will be provided. The size of the OFC will fully meet with the applications need of the HSR line and commercial exploitation of the Telecommunication Network by the HSR.

2) Synchronous Digital Hierarchy (SDH) network

This network is SDH network by Fiber Optic Transmission (FOT) with Optical Fiber Cable (OFC), which consists of STM-16 (2.4Gbps) as main communication network and STM-4 (600Mbps) as local communication network. Network using OFC has a feature that data can be transmitted with low loss so that there are no repeaters between SDH equipment. IP network shall not have important data like transmission of train control signal because the network requires high reliability.

Main communication network provides a high reliable multiple single paths in 4-fiber MS-SPR (Multiplex Section Shared Protection Ring) topology with STM-16 covering signal equipment rooms in stations and depots and OCC. The 4-fiber MS-SPR topology can be used by 100% for protection channel or for extra traffic and support ring switch and span switch. Local communication system provides voice and data signal paths in 2-fiber MS-SPR topology with STM-4 covering Substations (SS), Sectioning Post (SP) and Sub-Sectioning Post (SSP), etc. In the 2-fiber MS-SPR topology, 50% of the band can be used for protection channel or for extra traffic and only ring switch is supported.

A Network Management System (NMS) shall be installed at OCC. And the network shall be synchronized by the information based on the National Telecommunication Reference Clock (NTRC). This reference clock shall also be installed at OCC.

3) Gigabit Ethernet network

To support comparatively unimportant facilities for the HSR operation like CCTV, ticketing system maintenance management system and Wi-Fi network, etc., a Gigabit Ethernet network shall be used. This network shall use the same OFC as the SDH network. The network is supposed to be 10 Gigabit Ethernet network.

(3) Public Address (PA) system

PA system shall be provided to broadcast voice messages to passengers and staffs in each station. It includes a network of amplifier and speakers linked to the station. The system shall also be used for urgent broadcast in emergency and connect Passenger Information System (PIS) to inform passengers of information on train approaching and operation situation automatically.

(4) Closed Circuit Television (CCTV) system

CCTV system shall be provided for real-time and visual supervision through the color displays, selecting specific location or all the public area in stations as well as in OCC, tunnels, substations and depots. These can mainly be monitored at station master’s room and station cabin and at the OCC. CCTV system will consist of transmission equipment, remote camera, controller, monitor and video recorder. CCTV camera signals from selected area will be recorded by video recording device. And, CCTV monitor will be provided for displaying real-time pictures of each camera and recording playback.

(5) Passenger Information System (PIS)

PIS shall inform passengers of the state on the train operations such as timetable, departure and arrival of each train. And information for safety, train delay and emergencies shall be also displayed. OCC shall be able to control, monitor and communicate to any stations through PIS. And, operation control system installed in OCC shall also automatically control PIS.

(6) Telephone system

Telephone system will consist of dispatch telephone, PABX (Private Automatic Branch Exchange) and wayside telephone.

1) Dispatch telephone system

Dispatchers at OCC and staffs at each station, depot, workshop, maintenance depot, substation, signal & telecommunication equipment room, etc. will make communications with dispatch telephone. This telephone will be used for the purpose of conveying situation of train operation, electric power and signalling & telecommunications. Dispatchers at OCC shall have the highest priority to communicate to any stations, etc. via the dispatch telephone.

In the dispatch telephone, an integrated communication console will be provided at OCC. The console enables dispatchers to communicate with station staffs, depot staffs and maintenance staffs by dedicated communication line. And, concentration equipment will also be used to concentrate and control local telephone lines. Two type of concentration equipment will be provided. Master Concentration Equipment (MCE) will be installed at OCC to interface with Communication Console and Remote Concentration Equipment (RCE) will be installed at stations, depots and substations, etc. to interface with Multiple Function Dispatcher Telephone.

2) PABX telephone system

This system will consist of digital PABX and telephones installed at OCC, stations, depots and maintenance depots, etc. Each telephone will have dialing function to connect branch exchange system. The PABX can interface with public telephone line and dispatch telephone system.

3) Wayside telephone system

Wayside telephone sets will be installed every approx. 500m of interval in underground and tunnel section. And, in open section such as embankment and viaduct, they will be installed every approx. 3,000m. These telephones will be used mostly for maintenance work and also for emergency.

4) Voice Recording System (VRS)

A centralized digital Voice Recording System (VRS) shall be provided at the designated place to record all telephone conversations of all dispatchers at OCC and at stations.

(7) Clock system

This system is used to supply reference standard time to locations where time will be displayed, read and recorded. The system will consist of a master clock and slave clocks installed at OCC, stations, depots and maintenance depots. The main master clock will be located at OCC and acquires clock correction signal from GPS. The accuracy shall be within 1.0 second time error per week. Each local master clock shall be synchronized with main master clock at OCC using backbone network and provide other subsystems with standard clock signal. All the slave clocks shall be interconnected with related local master clock.

(8) Facility-SCADA (F-SCADA)

F-SCADA (Supervisory Control and Data Acquisition) can realize that dispatchers in OCC confirm and monitor condition of equipment and data on measurers for disaster information, so they can precisely instruct train crews and maintenance staffs and control train operations to prevent failures. F-SCADA continuously monitors equipment status in OCC. In case of equipment failure, the information is transmitted to OCC in real time and displayed on the monitor with buzzing sound. In addition, F-SCADA terminals are installed at each maintenance office and equipment failure information can be obtained there at the same time as OCC.

In the F-SCADA introduced in the Mumbai-Ahmedabad HSR corridor, the following items shall directly be monitored by OCC dispatchers:

- Stations equipment

  Elevator, Escalator, Ticketing terminal, Lighting, Shutter, Pump, Fire alarm, Ventilation, Air Conditioning and Engine Generator, etc.

- Signalling and Telecommunications

  ATP system, Interlocking device, AFTC, Electric Point Machine, Radio system, LCX, OFC, PA, CCTV, Clock system, PABX, Fire alarm, PIS, Cable, Power Supply, etc.

- Power distribution system

  Power distribution board

- Disaster information

  Wind, Rainfall, Water level in big river, Rail temperature, Earthquake and o utside temperature

In addition to the above-mentioned system, the HSR shall have measurers for rainfall, water level, wind speed, rail temperature and earthquake.

(9) Maintenance Management Information System

Maintenance Management Information System to record maintenance for rolling stock, track, power supply and signalling & telecommunications is described at the latter chapter in this report.

(10) Power Supply of telecommunications

Power supply for telecommunications needs to have reliability and high quality due to handling electronic device. Power for telecommunications will be supplied from each station and intermediate equipment room. Power supply devices consist of power distribution boards, insulation transformers with box housing, Uninterruptible Power Supply (UPS), rectifiers and batteries.

(11) Cable for telecommunications

Cables for telecommunications are basically desirable to use non-halogen flame retardant cable except OFC.

9.11.3 Cost Comparison of S&T Systems

(1) Cost comparison based on the differences in system combination

Table 9.11-10 shows cost comparison between combination of Digital-ATC System and the dedicated Train Radio System using LCX and that of ETCS Level-2 and GSM-R in the Mumbai-Ahmadabad HSR. The study team considered that the proposed system which consists of Digital-ATC and Train Radio System using LCX has the almost same cost as the system including ETCS Level-2 with GSM-R.

Table 9.11-10 Cost Comparison Based on the Differences in System Combination

System combination	Digital-ATC + Train Radio System using LCX	ETCS Level-2 + GSM-R
S&T cost	INR 24,595 million	INR 25,628 million

Source: Study Team

(2) Cost comparison between the joint F/S and the Pre-F/S

Table 9.11-11 shows cost comparison between the proposed system in the joint F/S and that of the Pre-F/S implemented in 2009.

Table 9.11-11 Cost Comparison between the F/S and the Pre-F/S

Report	F/S (2014)	Pre-F/S (2009 -> 2014)
S&T cost	INR 24,595 million	INR 37,197 million (*)

*The present escalated cost based on estimation cost in 2009 (Inflation rate of 57.75% using IMF)

Source: Study Team

About contents proposed in the Pre-F/S,

-Cost of OCC-related system is included in S&T category.
-Many signal routes and cross sections are needed for bi-direction operation.
-The HSR has equipment for interoperability and replacement of existing system.

The above factors may cause occurrence of the cost difference shown in Table 9.11 -11.

9.12 Operation Management System

9.12.1 Roles and Requirements of Operational Control Center

As one of element which support to “Safety and Sustainable Train Operation in high-speed rail ", it is needless to say, Operational Control Center (OCC) is significant. Following matters are roles and requirements for OCC.

Role:

- Management of Train Operation
- Supervising

  Track Facilities (Permanent Way, Power Supply, Signaling, communication, etc.)

  Weather Condition (strong wind, heavy rainfall, earthquakes, etc.)

Requirement:

- Real time Information Tracing of Train and Facilities
- Trouble Shooting in case of accident

  (Operation Arrangement, Train-Set Distribution, Driving Crew assignment, etc.)
- Notification for Station, Crew, Maintenance Depot and Passengers

To satisfy these requirements, OCC has also changed with technological progress and transition of transport year by year.

9.12.2 Historical Progress of Train Operation Controlling System

The first step of a Train Operation method is the leading by stations. Transport officers, who substitute the mission of train operation only for stationmaster, were placed in each station. They decided to the operation schedule, arrival and departure of the train, at the adjacent station each other. Also there were traffic dispatchers, however, dispatchers had no real time information about traffic situation, such that train location, delay time and so on, in this method. All information depends on station. So they had to confirm with each station staff and recorded the actual operation. Therefore, this method is not suitable for high density and high speed train operation.

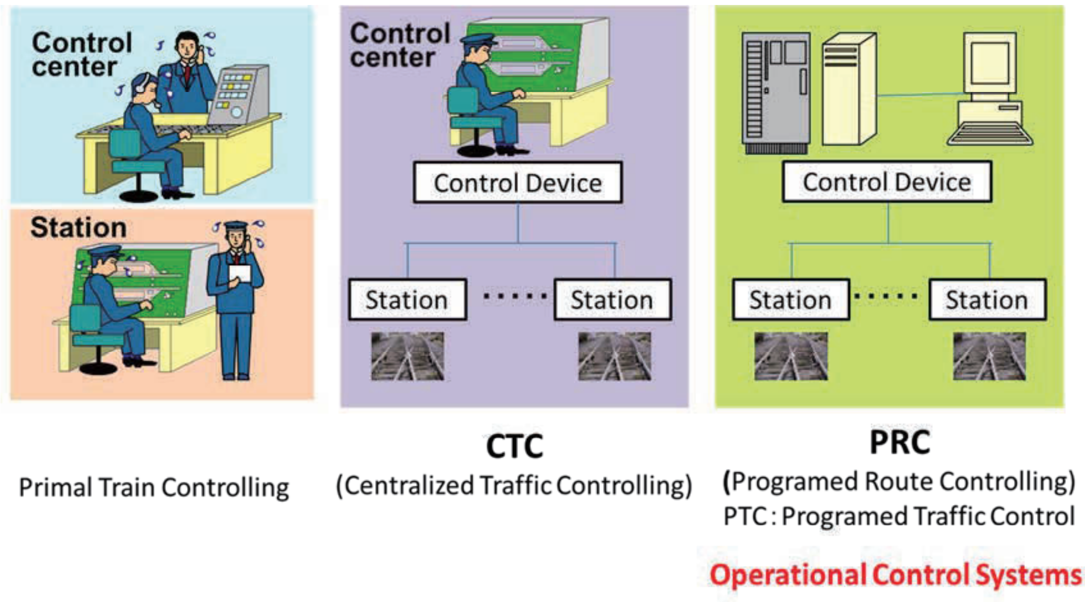
The second step is the Centralized Traffics Controlling system (CTC). It was developed for single track and local lines in United States of America (USA) in 1927 to provide efficient train operation. Dispatchers controlled the all train passing route from central controlling center, instead of Transport officers at station. The device was composed of relay logic circuit.

When Japanese National Railways (JNR) revealed the Tokaido Sinkansen line in 1964, CTC was applied to the High Speed Railway and trunk line. It was the first success in the world. JNR regarded that centralized operation management was essential in high-speed rail in particular. Because High speed Train operation needs “unified high speed decision-making”. This system was composed of solid-state transistor devices. At this period, traffic dispatchers were controlling the train passing route by manual.

And then the train Operation Controlling System has developed, which is able to control the train route automatically by computer. This is the Programed Route Controlling (PRC). But when the traffic incident occurred, it was necessary to change the train schedule. So that the man and machine interface device, which were able to change the train schedule, were added. In general, this is the Operational Control System

In 1972, when the Sanyo Shinkansen, which was extended from the Tokaido Shinkansen to west, was started on services, in this opportunity JNR adapted the PRC, named COMTRAC(Computer aided Traffic Controlling system) . This system was automatically controlling the train route by computer with the inputted scheduling data beforehand.

In this way, Operation Controlling System has been developed and applied for not only high speed railway but also the city railway. It has been one of the symbols of the modern railway operation.



Source: Study Team

Figure 9.12-1 Progress of Train Operation Methods

9.12.3 Example of Operation Controlling System

(1) Japanese Shinkansen

1) COMTRAC and SIRIUS

As mentioned above, COMTRAC has been developed for Tokaido and Sanyo Sinkansen. It is composed of three Sub-systems, as follows.

a) EDP（Electronic Data Processing Computer） system

-Drawing a train diagram on the computer and Submitting diagram concerning section

b) PRC（Programmed Route Control） system

-Controlling the train passing route and diagram arrangement in case of accident

c) MAP（Man-Machine Advanced Processor） system

-Displaying the traffic information to mimic display by human and machine interface

SIRIUS (Super Intelligent Resource and Innovated Utility for Shinkansen Management) is the new system for Kyuushu Sinkansen and almost same performance for COMTRAC. Due to SIRIUS and COMTRAC are connected on line and real-time, it is possible to provide the direct through train operation between Sanyo Shinkansen and Kyushu Shinkansen.

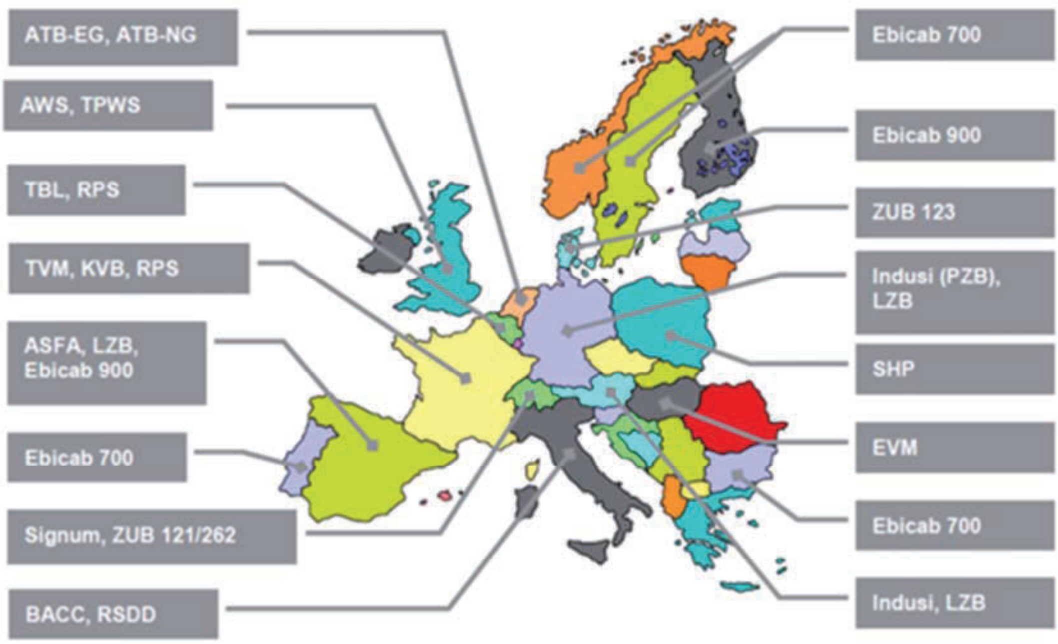
2) COSMOS (Computerized Safety, Maintenance and Operation Systems of Shinkansen)

The East Japan Railway Company (JR East) developed new two types of Operation Controlling System by using of the autonomous decentralized system in the late of 1990s. One is COSMOS for Japanese High Speed Rail, Tohoku and Joetsu Shinkansen and another is ATOS (Autonomous decentralized Transport Operation control System) for existing commuter lines in greater Tokyo area..

COSMOS is consisted in 7 data linked sub-systems which are Transport Planning, Operation Control, Rolling stocks Control, Maintenance Work Control, Station Yard Control, Centralized Monitoring and Power SCADA. It is comprehensive train operation Controlling System.

(2) Current European OCC

There are many kinds of Automatic Train Protection system (ATP) in European countries. This situation is one of the obstructions for the cross border train operations between some countries. European Union (EU) initiated the development of unified ATP and OCC systems since 1990s. Unified ATP is European Train Controlling System (ETCS) and OCC is European Railway Traffic Management System (ERTMS). ERTMS is composed of ETCS and GSM-R (Global System for Mobile communications - Railway)

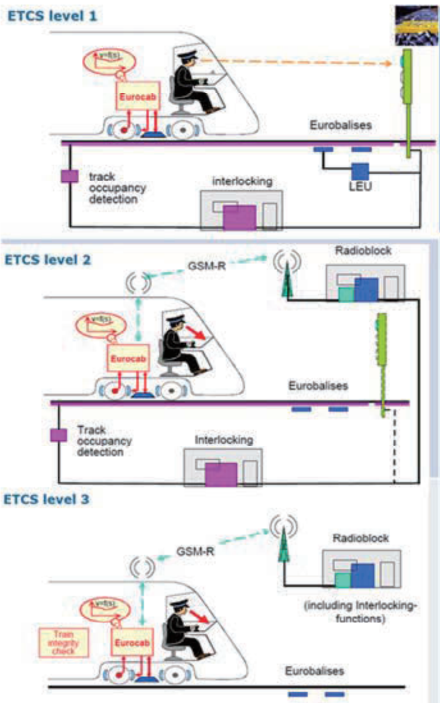


Source: http://www.ertms2012.eu/fileadmin/Content/Downloads/2011/pdf/InfoOnERTMS.pdf

Figure 9.12-2 ATP Methods in Europe

ETSC is categorized into 3 levels as below, and "Level 1 and 2" adapt fixed block section method and "Level 3" is flexible type. But German signaling system LZB

(Linienzugbeeinflussung), it has already realized flexible type block section. And also Equipment replacement will be still future.



Fixed Block Section	➢Wayside signal ,Track Circuit ➢Same performance of Japanese ATS ➢Transmission method of wayside and on board : Transponder (Euro Balis)
Fixed Block Section	➢Transmission method of wayside and on board: GSM-R ➢Same performance of Japanese ATC ➢Train Location Detecting by Track Circuit and Transponder
Flexible Block Section	➢Integrated On Board Device and GSM-R ➢Train Location Detecting by Transponder only ➢No wayside signal facilities

Source: Study Team

Figure 9.12-3 ETCS and its Categorized

(3) Actual Statas in Asia

1) China

China High Speed Rail adopted CTCS which was based on ETCS Technology. As well known, the regrettable collision accident, which was caused of signal trouble and unappropriated human procedure, occurred in 2011. Although the operational control system was not a direct cause of the accident, all railway engineer should be lesson and learning from this accident that the system integration is important, not only system technology but also human handling and operation.

2) India

According to UIC report, already there are two installations of ETCS lines and one of which is under construction in India. On service line are existing lines and installed ETCS/LVEL1.

24. INDIA

INDIA

Company	Line	Section length (km)	Type of Tracks	ETCS Level	Status	Year of the contract	In service since year
IR	Chennai -Gummudipundi	50	DT	1	Commercial operation	2005	2008
IR	Delhi - Agra	196	DT	1	Commercial operation	2005	2009
IR	Gummidipundi - Elavur	10	DT	1	Under construction	2009	2014

Company	Name of Loco	N. of trains	OBU	Type of Loco	ETCS Origin	Status	Year of the contract	In serv since year
IR	WAP 5 & 7	35	35	Loco	Retrofitted	Commercial Operation	2005	2007
IR		42	84	EMU	Retrofitted	Commercial Operation	2005	2007

Figure 28: IR EMU

80

Source: ATLAS ERTMS 2012, UIC

Figure 9.12-4 Current Situation of ETCS in India

(4) Concern about ETCS / ERTMS introduction

Exactly ETCS/ERTMS project is important for not only European railway operators also manufactures and government sectors. Now ERTMS Level 2 is on service for the High Speed Rail in Italy and Spain. This function is limited for only train operation and other function, for example the passenger information function, is not complete yet.

This project is delay for some reasons as follows,

1-Basic system is designed for huge traffic volume countries, for example France, Germany, so that there are many extra functions. It may be too huge system for small traffic volume countries.

Usually, it is dearly difficult to accommodate downsizing from huge system. Because it is needed to confirm of program module functions again and added cost. System Providers would be preferred to recover the initial investment cost. Therefore, the customers would like to put up with the extra function and cost.

2-GSM-R is one of the important components for ETCS. GSM is popularized in many countries, however, there are many Special functions each countries. So it is difficult to specify unique.

3- There is not yet the man-machine interface in common for the transportation management system of the OCC, there is on board system only. "Europtirail" which is supporting system, can display the position and delay information of the train and including some static function, but there is no Diagram arrangement function.

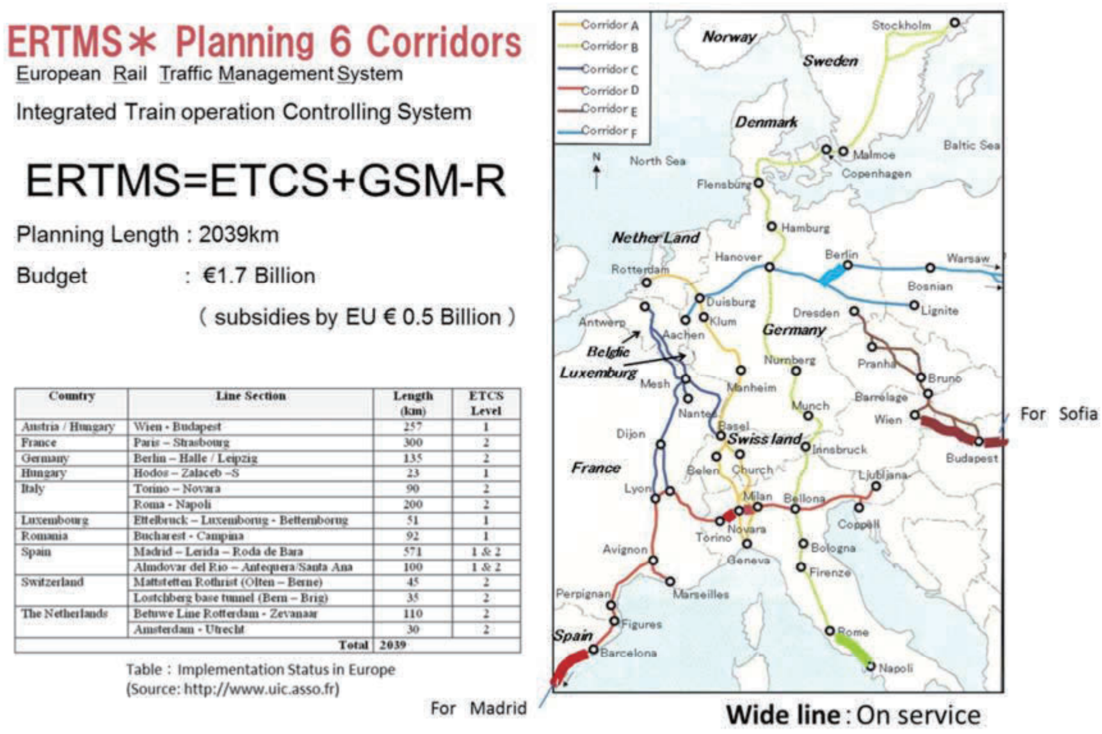
Exactly European system, ERTMS, is the great system of unprecedented concept, because final target may be covered whole Europe and adapt the train controlling by wireless radio at Level 3 for furfure. However this system is so huge system that there are several technical and political barriers. For example technical specifications are revised many times and they have to issue more than 20 European languages. And due to long project term, Basic technique progress so hurry day by day that it is difficult to catch up. ERTMS has adapted GSM-R for the high speed and large capacity communication method, but up-date communication method is LTE (Long Term Evolution).

First of beginning, the purpose of this system is available for the interoperability in European Railways, however, there are three places carrying it only. Some countries have doubts about the effect of the introduction and complain the delay of the construction progress.

And more ERTMS has been developed for the dedicated route controlling function only so that passenger information service function is not yet practical using. This function will be contributed for the punctual train operation, mentioned in detail 9.9.5(3).

Therefore study team recommend that Operational Control System, which is confirmed the compatibilities with Digital ATC, is suitable to compare the ETS/ERTMS, including China High Speed rail system, for any experiences and closed section of the high speed rail operation.

Finally adapting Digital ATC, which have already inspected and confirmed for all function with proposed system in detail, as a signal system, is advantage for shortening the installation term and to contribute the price down. Study team strongly expresses that High Speed Rail operation should be adapted due to actual result and proven safety system, which is based on the COSMOS and COMTRAC technology, sufficiently.



Country	Line Section	Length (km)	ETCS Level
Austria / Hungary	Wien - Budapest	257	1
France	Paris – Strasbourg	300	2
Germany	Berlin – Halle / Leipzig	135	2
Hungary	Hodos – Zalaceb –S	23	1
Italy	Torino – Novara	90	2
	Roma - Napoli	200	2
Luxembourg	Ettelbruck – Luxemborug - Bettemborug	51	1
Romania	Bucharest - Campina	92	1
Spain	Madrid – Lerida – Roda de Bara	571	1 & 2
	Almdovar del Rio – Antequera/Santa Ana	100	1 & 2
Switzerland	Mattstetten Rothrist (Olten – Berne)	45	2
	Lostchberg base tunnel (Bern – Brig)	35	2
The Netherlands	Betuwe Line Rotterdam - Zevanaar	110	2
	Amsterdam - Utrecht	30	2
	Total	2039	

Source: http://www.uic.asso.fr

Figure 9.12-5 ERTMS Situations in Europe

9.12.4 Modern and Robustness system configuration

(1) Robustness network

At the first of beginning, CTC and PRC were tree type system, which were composed of central computer and station devices. After then system composition have been progressed accompany with the progress of information technologies.

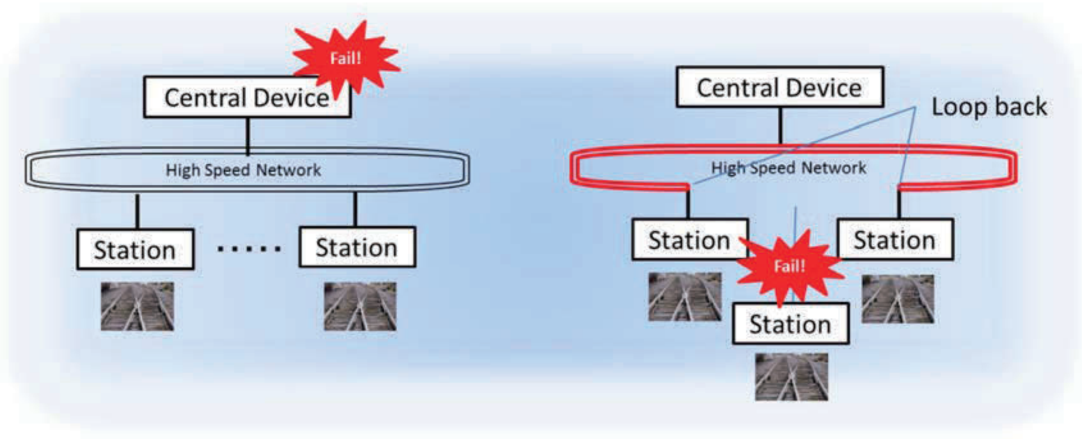
In recent technology, the autonomous and decentralized system, which consisted of central computer and station computers connected high speed and large capacity network cable, is current. The feature of this system is sharing the same diagram between central computer and station ones.

The advantage of this method is follows,

1- If central computer is failed but no problem each station system, it is possible to continue the train operation.

2- If some station system is failed, it is possible to continue the train operation by network loopback function.

And more, it is possible to set up station by station. So that construction and installation work is simple and easily.

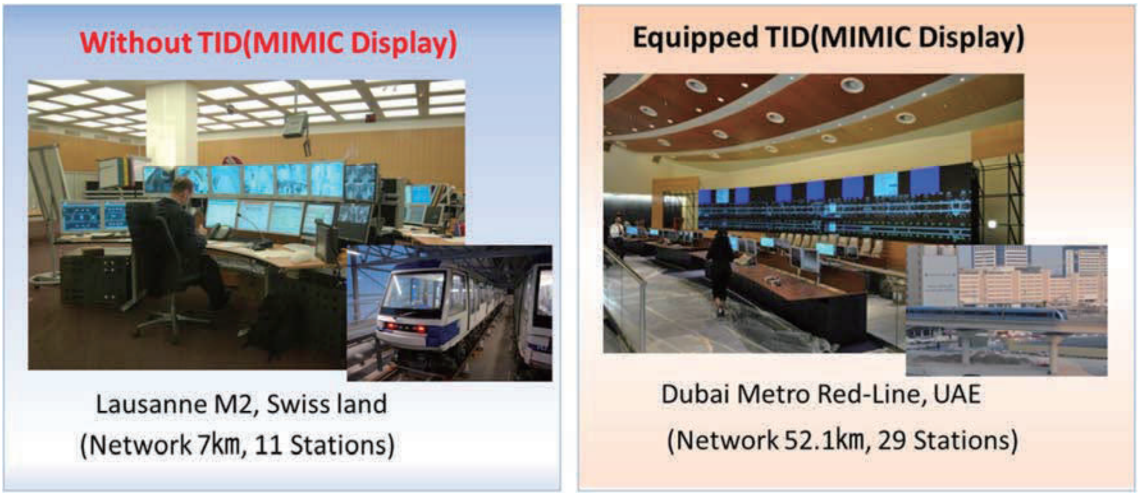


Source: study team

Figure 9.12-6 Advantage of Autonomous and Decentralized System

(2) Without Train Information Display (TID)

Traffic information display or MIMIC Display is a one of the symbol of OCC. Recently, as shown in the photo on the left below; there is also OCC that is without such a panel.



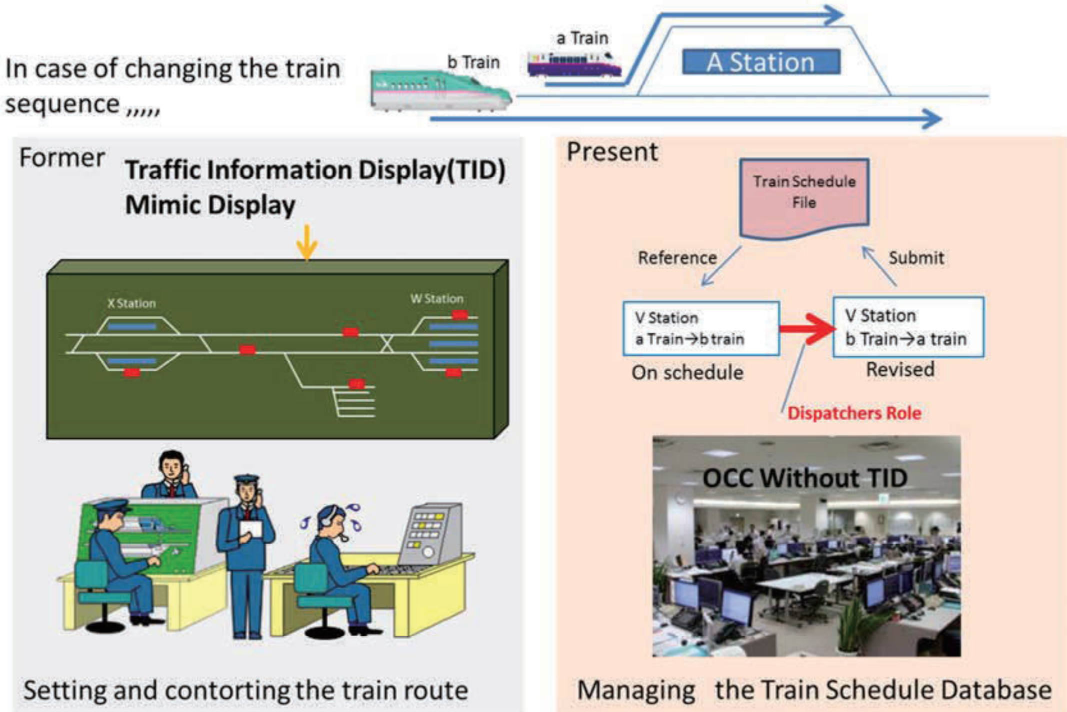
Source: Study Team

Figure 9.12-7 Comparison of Deferent Type OCC

This display which shows the traffic information, such that track layout, train location, delay time and so on, was the symbol of the train controlling center. However, COSMOS and ATOS system expelled it from the controlling center. That is why these systems have changed dispatchers' role.

In case of changing the train sequence at some station, dispatchers in the former CTC decided and setting the train route by switches. But dispatchers in new system, COSMOS and ATOS, arrange the train schedule diagram database without contradiction.

Therefore, COSMOS and ATOS bring epoch-making milestone for the Operation Controlling..



Source: Study Team

Figure 9.12-8 Change of the Dispatchers' Roles

9.12.5 Controlling Center Management

Controlling Center staff should be together same floor and room without bulkhead to share the information, because an immediate determination is essential in the case of incidents.

(1) Staff Responsibilities in OCC

1) Managing staff

In work shifts of 24 hours until 9:00 the next day from 9:00 in the morning, they are representative manager of this OCC.

2) Traffic Dispatchers

They are in charge of train operation and arrange the train diagram in case of traffic obstacle. Also they inform to concerning section such that station, depots, driving crews.

3) Operation Dispatchers

They are supporting Traffic Dispatchers to distribute train sets or assign driving crews. In charge of Passenger Service is information providing and customer service.

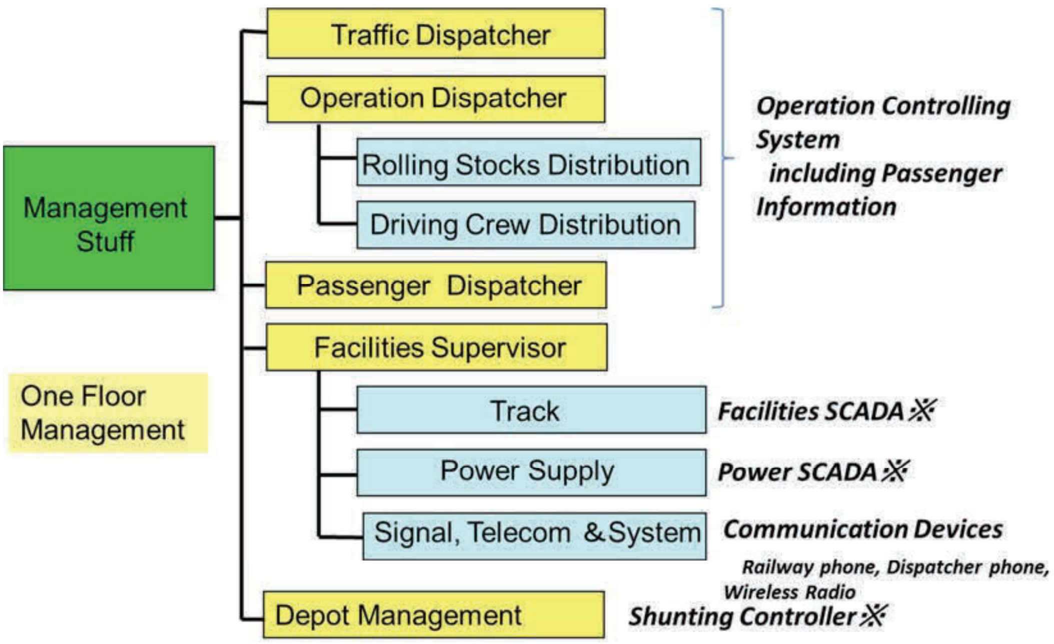
4) Facilities Supervisor

They are supervising track facilities, such that Permanent Way, Power Supply, Signaling, communication. Facilities-SCADA and Power-SCADA are proposed by Signaling and Electricity Expert. When monitor of SCADA inform alarm or warning, they immediately confirm the detail situation and request to Traffic Dispatchers.

5) Depot Management Staff

They are controlling the shunting in depot and prepare the in/out train for main track.

Shunting Controlling Panel is provided by Signaling Expert.

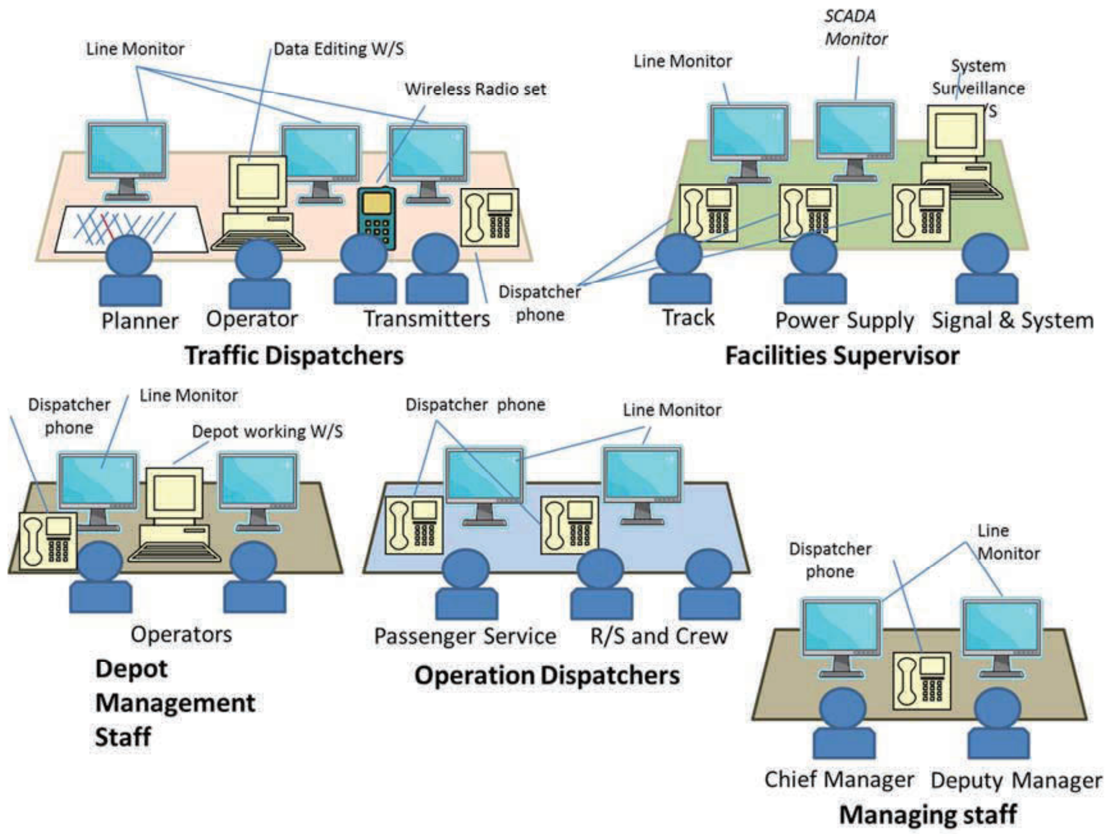


System or devise with ※ :consider and prepare by each section

Source: Study team

Figure 9.12-9 Organization Chart in the Controlling Center and Devices

Their working Layout is shown below figure.

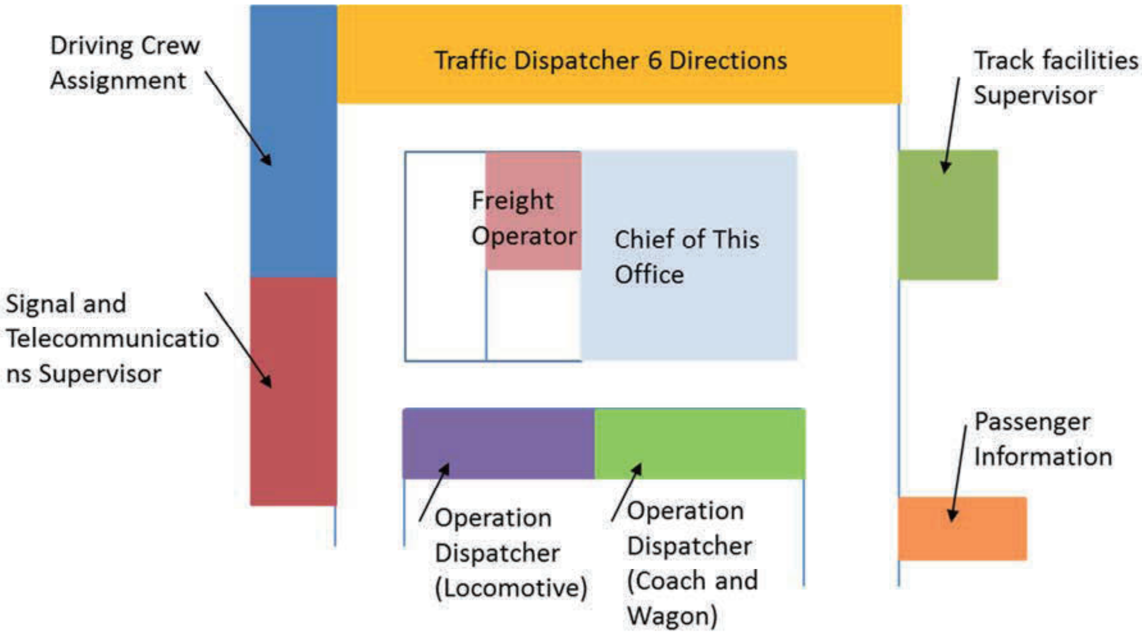


Source: Study team

Figure 9.12-10 Center Layout

(2) Comparison with the current Indian Railway

The proposed the role-sharing and organization chart of OCC is confirmed almost as same as OCC of current Indian Railways through the field Surveillance by study team. Study Team visited at Delhi District Railway Management Office on 10th September, 2014.



Source: Study team

Figure 9.12-11 Indian Rail OCC

(3) Importance of the Passenger Information

One of the features of the proposed system is relation between the management system and passenger information. As usual, Passenger information System is one of the communication devices. But in this proposed system, passenger information system is linked with Operation Management system to be following the diagram arrangements. In other words, it is a function to automatically change the information display at stations, when the train sequence has changed.

Therefore concepts of this proposal are minimum function and reasonable cost. Proposal system is simple configuration for the train operation but remarkable function is including the passenger information function. This function seems to be very easy but it is very difficult and nerves, because it provides information for customers.

This function contributes to the punctual train operation. By displayed information, customers can get the train of theirs exactly. At the Tokyo terminal of JR East High Speed Rail, there are two platforms and 4 tracks, and provide more than 300 trains daily and minimum head way is 4 minutes. On the concourse, each platform and track train information, destination, departure time, reserved and non-reserved cars, and so on, are display for customers. Information of 3 trains is displayed at every track so information of 12 trains is displayed always. When one train left the station, the display immediately revise the train information.

Customers confirm their train and car’s number by themselves and wait for train at the platform. Like this train leave station on time without customers’ confusion.

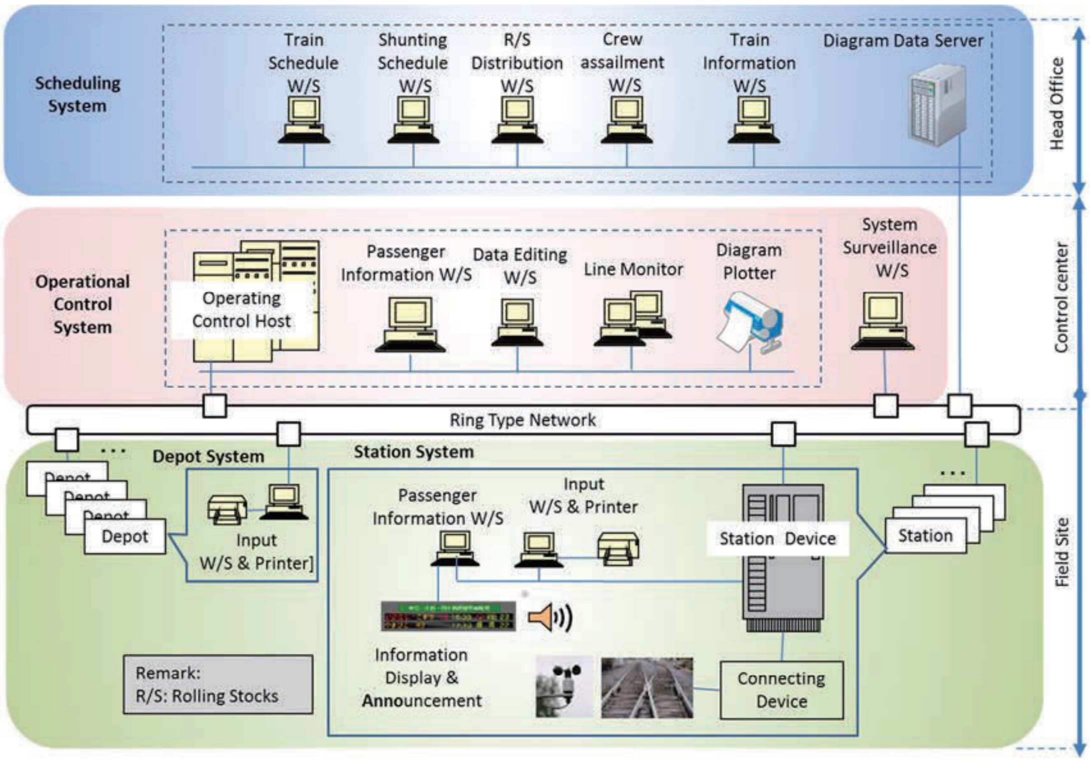
Source: Study team

Figure 9.12-12 Shinkansen Platform at Tokyo Station

9.12.6 Proposed Train Operation Controlling System

(1) Configuration

System should be introduced Autonomous decentralized system which consist of central system and local system, such that stations and each depot, with connected by high speed and large capacity communication cable.



Source: Study team

Figure 9.12-13 System Configuration

2) Central System

As follows, it should be consisted of 2 sub system and the System Surveillance.

a) Scheduling System

This system consists of some work stations (W/S), concerning the train schedule, passenger information etc., and file server with the redundant structure.

b) Operational Control System

This system consist of the dual host computer, it is hot standing by, some w/s which can be to change the timetable adjustment and line monitors which can display the whole line situations, detail station situations, each train diagram.

c) System Surveillance

This monitor is supervising and showing each system components situation,

If some components are failed, suddenly systems monitor alarm and show the message on the display.

3) Local system

a) Station

This is consisting of communication device and signaling-interlocking devise which is connected with wayside devices and passenger information device. The system receives the train diagram daily and when train schedule has changed by traffic dispatchers, it is available to change the train route and passenger information.

b) Rolling stocks and Driving Crew depot

This is w/s which receives distribution or assignment scheduled from the central server and reply information to central system.

(2)Function

a) Making the Train Operation Scheduling
There are 2 schedule modes, one is Present diagram and another is revise diagram for future, and prepares the basic and temporally train operation schedule. Operation schedule are reserved 180 days maximum in scheduling server.

Scheduling Section of Traffic Department draw the basic train diagram. It is impossible to train operation only basic diagram, so that Scheduling Section adds the shunting diagram at the Rolling stock depot to basic diagram. Also this section inputs Passengers' information which is displayed on information boards or automatic announcements at station.

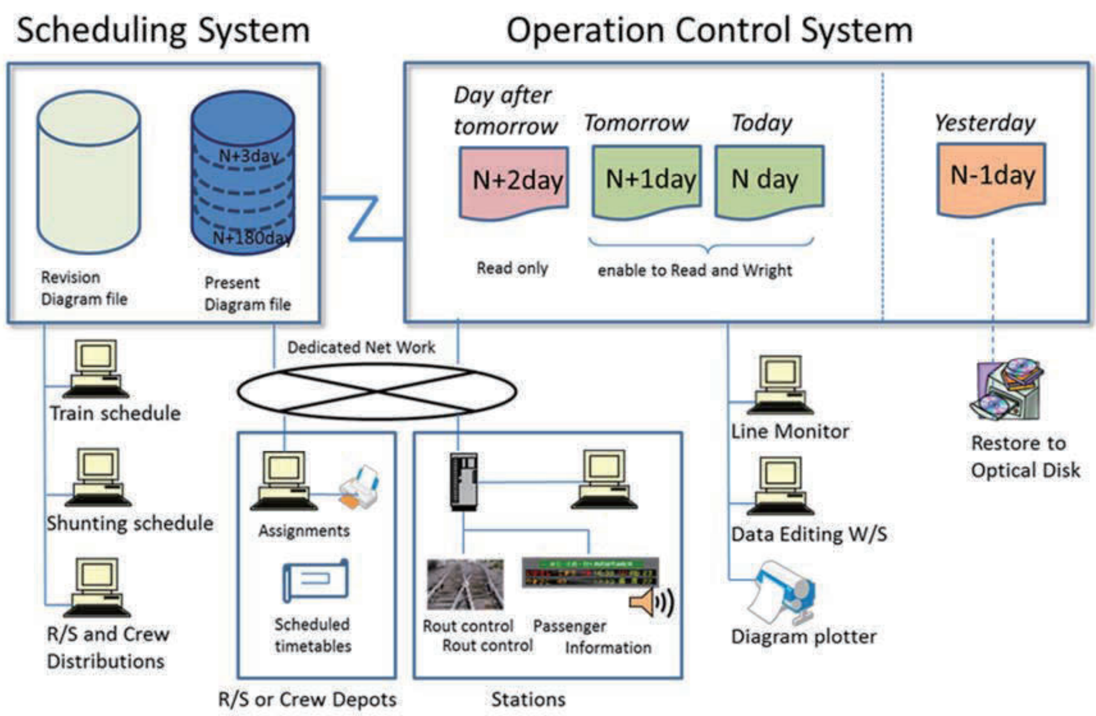
Operational planners also inputs the Train set distribution and crew assignment. Each operating plans are submit to the Rolling stocks depot or crew office, Depot and office assign for resources and reply to Operation planners.

b) Transfer Train Diagram from scheduling system to operation system and each field
Every day, diagram transfer from scheduling system to Operation Control System. And then Operation Control System generate the "Operation Diagram" and also send to concerning system, such that station, depots. Operation Control System keeps 4 day diagram which are yesterday, today, tomorrow and the day after tomorrow. In other words, the train schedules of up to 3 days are managed in the Operation Control System and more future diagram are managed in the scheduling system.

The actual result diagram of the previous day is stored in storage media.

c) In case of Train Operation Obstacle
Line Monitor displays the location and delay time of each train and weather situation, rain fall wind speed and so on, on the line. In case of train operation obstacle, Traffic dispatchers arrange the train diagram from Data Editing W/S. Changed schedules are submitted to the host computer and the computer check the contradiction. If there are some contradictions, reply to despatchers by alarm or caution messages. Changed schedule data without contradiction is transmitted to station system and station system is setting the train route by updated schedule.

d) Prevention for Natural Hazard
Track conditions are supervising by Facilities-SCADA. When some incident occurs, Terminal monitor of Facilities-SCADA, which is set on OCC, informs alert or warning to Track Facilities Supervisors. Track Facilities Supervisors inform and request to traffic dispatchers, then traffic dispatchers set the temporally limited speed section from Data Editing W/S.



Source: Study team

Figure 9.12-14 Date Flow

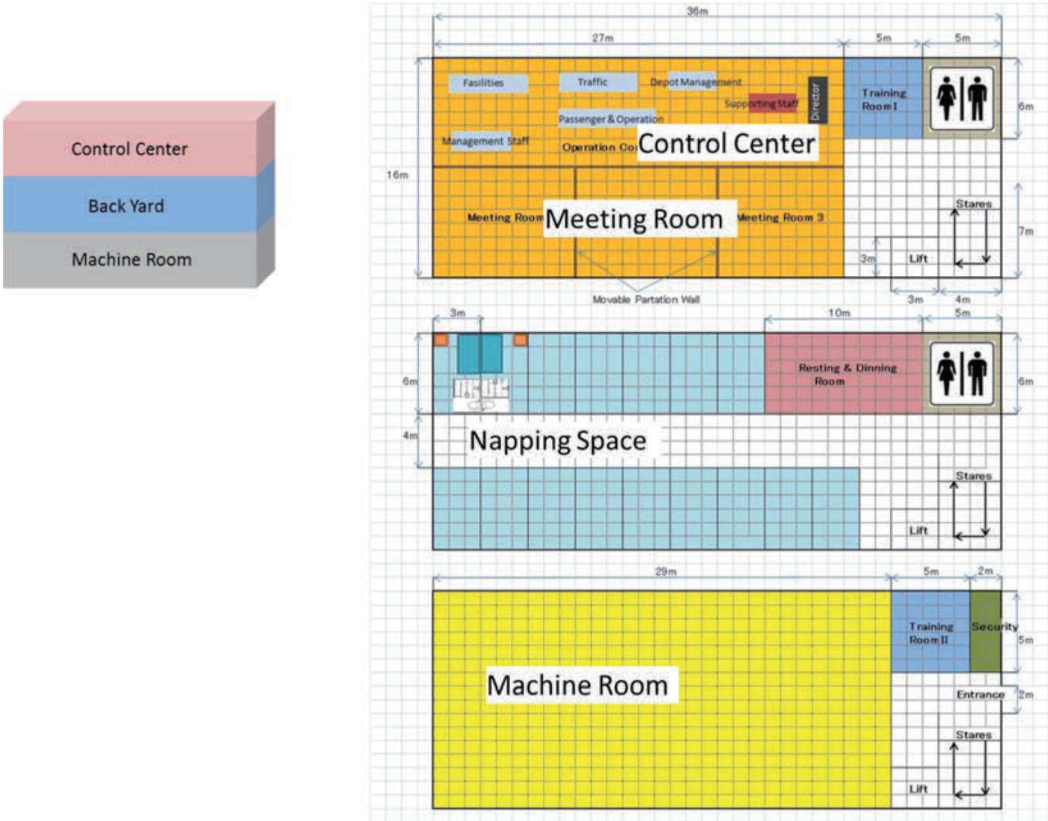
9.12.7 OCC Building

OCC building is assumed to be three-floors; ground floor is machine room, middle floor is back yard including Napping and catering space, top floor is OCC, such as the following.

Half of the OCC is a meeting room. In case of accident, this is used for "Accident Response Office". And also for the machine replacement, new generation system will built up on this space. In the same way, not only the current system to the Machine room, so as to secure a space for the system replacement.

As candidate sites of OCC, it is assumed the same area of Sabarumati Depot and Work shop. In this case, that the shunting operator and the operation panel of maintenance Depot should be placed in the OCC, because the communication between OCC and Depots is significant in case of accident.

For alternative idea, OCC Building builds nearby Head Quarters Building. The advantage of this is that it is easy to get the supporting from the Head Quarters and to be suitable for an information transfer related agencies, the Ministry of Railways, the police, to the public relations and so on.



Source: Study team

Figure 9.12-15 Layout of OCC Building

9.12.8 Backup Function of OCC

This is a question from Indian side at the subsystem Work shop which was held on 8th September. Study team propose that it is no necessary such redundancy equipment, due to follows reasons,

1) High speed OCC should be unified organization.

2)Due to 3days Diagram is submitted from Host computer to field computer reason, it is possible to operate the train at least during 3 days, (If disturbing of train operation more than 4days, it might has occurred so serious incident.)

3) Due to exclusive rule reason, it is difficult to build up the hot standing by system. Redundancy system must be built up cold standing by.

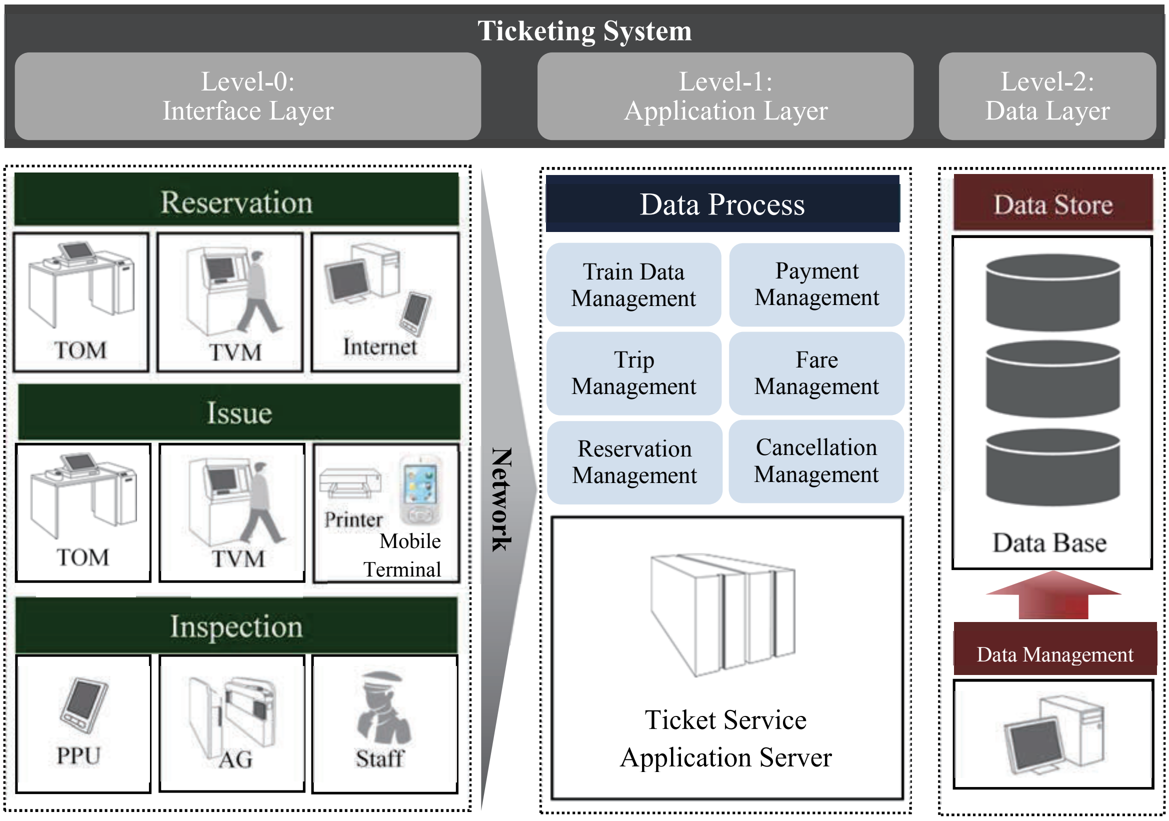
However, Delhi Metro has already equipped BCC (Backup Controlling Center) which is using training equipment as usual. But in case of problem of OCC, this equipment suddenly start up for actual system to copy the train diagram and arrange the train location. When considering the basic or detail design, study team suggest as future subject the necessary of backup control center.

9.13 Ticketing System

9.13.1 Ticketing System Structure

Tickets are most often used for receiving fares in exchange for railway transportation services provided for users. Tickets, on which the information on the service contents and the fare is shown, are given users who have paid fares for getting services. This process is ticket issuing. To get reserved seats, passengers need to reserve them. In this case, ticket issuing follows reservation. The railway business operator can confirm by checking the ticket that the user has a legitimate right to transportation services. This checking process is ticket inspection.

The ticketing system is a computerized system for effectively managing the processes of reservation, ticket issuing and inspection with a view to improving convenience for users. This system is generally built up from three layers as shown in Figure 9.13-1: the interface, application and data layers.



Note:
TOM: Ticket Office Machine
TVM: Ticket Vending Machine
PPU: Portable Processing Unit
AG: Automatic Gate

Source: Compiled by Study Team

Figure 9.13-1 Ticketing System Structure

(1) Interface Layer

This layer provides an interface between users and the application layer. The TOM/TVM/PPU and the online system are offered as an interface for facilitating reservation, ticket issuing and inspection for both users and station clerks. Convenience, operability and functionality are important for the interface layer because it constitutes a direct contact with users.

(2) Application Layer

The application layer handles requests from the interface layer and delivers the results. In general, the application layer that implements a processing program is linked with the interface layer via the network. Upon request, the ticketing system properly conducts transactions, including reservation management, cancellation management, route/fare management, train data management, and payment management. Real-timeliness, responsiveness and throughput are important for the application layer because requests from users are handled simultaneously.

(3) Data Layer

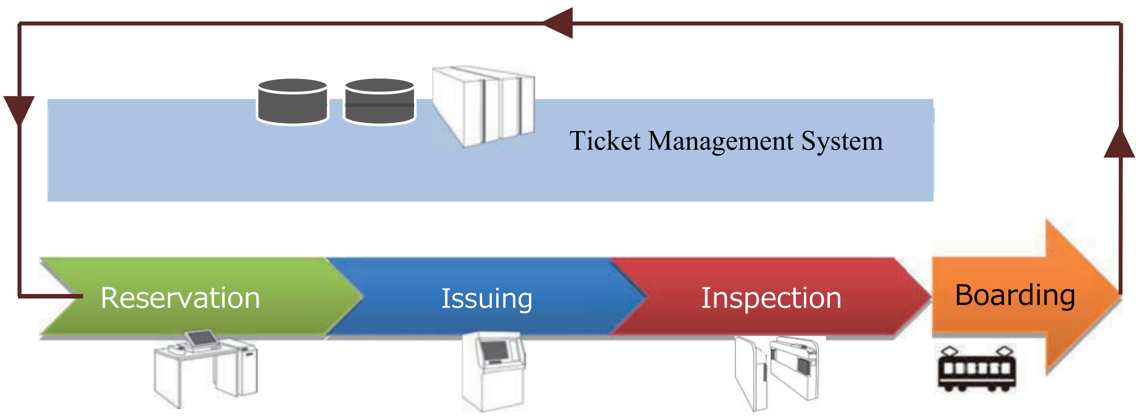
This layer manages data used on the application layer. As necessary, the application server extracts data from the data layer, renews and stores it. Data confidentiality and integrity are important for the data layer, so data is encrypted and disks are multiplexed.

9.13.2 Processes Handled by the Ticketing System

The ticketing system handles reservation, ticket issuing and inspection processes, as shown in Figure 9.13-2. The reservation process is a process in which passengers book tickets in a prescribed way: for example, by using TOM/TVMs or the online system. In the ticket issuing process, booked tickets are issued through TOM/TVMs according to the reservation number. When a reservation is made through a TOM/TVM at the station, reservation and ticket issuing are processed in a sequence.

In the ticket inspection process, passengers' tickets are checked to confirm their validity. Inspection is conducted at the time of both entering and exiting the concourse, or on board.

The data used throughout the ticketing system is stored in the database connected to the application server. When any of the processes is done, a relevant channel on the interface layer inquires the application server, and then receives transaction results as an answer from the server. Multiple requests are sent concurrently from station machines and the online system, so the application server needs to effectively respond to them and ensure that no improper transactions occur, including dual issuing.



Source: Compiled by Study Team

Figure 9.13-2 Ticketing System Cycle

9.13.3 Ticketing Systems for High Speed Railways in Other Countries

The ticketing system is different in structure according to the operation/management system, equipment specifications, and services offered. Therefore, research was carried out concerning ticketing systems for high speed railways in other countries. Table 9.13-1 shows its findings. Here, they are discussed from the following three points: (1) ticket medium, (2) reservation and ticket issuing, and (3) ticket inspection.

(1) Ticket Medium

Tickets used in the surveyed countries are classified into four medium: paper tickets, magnetic tickets, IC cards and e-tickets. Conventional paper and/or magnetic tickets are used in all the countries surveyed, while e-tickets are also used for almost all the railways because they are very convenient for reservation and ticket issuing.

(2) Reservation and Ticket Issuing

There are two reservation methods found. One is going to ticket windows or TVMs at stations for reservation. The other is using the online system on the Internet. The online reservation system has already been introduced for almost all the high speed railways, and many passengers book tickets in advance via the Internet. Such tickets can be received at the station, or gotten by mail. If they are e-tickets, they can also be printed at home. Moreover, services that make it possible to download and display ticket information on mobile terminals, such as smartphones, are spreading. Internet reservation and e-tickets are popular among users due to their convenience. High speed railways are expected to be used more often by business people who try to use their time effectively than existing railways. Such business people tend to use the online system for reservation, rather than waiting in line at ticket windows, so a need for internet reservation is probably greater for high speed railways than for existing railways. The wider use of such mobile terminals as smartphones, which enable reservation even outside offices, is expected to further accelerate this tendency.

(3) Ticket Inspection

Inspection methods are different according to ticket medium. In the case of a magnetic ticket or IC card, its validity is checked by a reader equipped at the automatic gate. The validity of an e-ticket is confirmed by reading information printed or displayed on the mobile terminal.

Some railway operators separate the concourse for the high speed railway from other concourses, and conduct inspection at the entrance to the HSR concourse to allow only valid ticket holders to board the train. Other operators do not conduct inspection before boarding but on board. The latter method is often used in Europe, as is shown in the table. This is because many railway companies do not separate HSR lines and platforms from ones for the existing railway. On-board inspection is conducted regardless of whether inspection at the entrance to the concourse is conducted or not, because it is necessary to check passengers who do not use the seat and train designated on the ticket. On-board inspection has been done by the conductor according to the printed chart of reserved seats, but now the use of PPUs on which the reserved seat information is downloaded from the application server is gradually becoming common to make sure that the passenger’s ticket is consistent with the given information.

Table 9.13-1 Ticketing Systems for High Speed Railways in Other Countries

Item		Eurostar (France, UK, Belgium)	Pendolino (UK)	Javelin (UK)	Train à Grande Vitesse (France)	InterCity Express (Germany)	Sapsan (Russia)	Acela Express (USA)	Korea Train eXpress (Korea)	Taiwan High Speed Rail (Taiwan)	China Railway Express (China)	Shinkansen (Japan)
Ticket Medium		Paper Magnetic ticket e-ticket	Paper Ticket e-ticket Mobile Device	Magnetic ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Magnetic ticket(Card) e-ticket	Magnetic ticket(Paper) e-ticket	Magnetic ticket(Paper) e-ticket (Card, Mobile Device)
Reservation	Reservation method	Ticket window TVM Internet reservation	Ticket windows TVM Internet reservation、	Ticket windows TVM Internet reservation、	Ticket windows TVM Internet reservation、	Ticket windows TVM Internet reservation、	Ticket windows Internet reservation	Ticket windows TVM Internet reservation Phone On board	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation
	Payment	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card
	Seat reservation	All for reserved seat	Reserved and non-reserved seats	All for non-reserved seats	All for reserved seat, non-reserved seat during busy season	Reserved and non-reserved seats	Reserved and non-reserved seats	All form non-reserved seats but issued ticket number is fixed to the number of seats	Reserved and non-reserved seats	Reserved and non-reserved seats	All seats for reservation	Reserved and non-reserved seats
Ticket Inspection	Inspection at entrance to concourse	Inspection by Automatic Gate	No inspection	Inspection by Automatic Gate	No inspection	No inspection	No inspection	No inspection	No inspection	Inspection by Automatic Gate	Inspection by Automatic Gate	Inspection by Automatic Gate
	On board Inspection	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor No inspection in some lines.
Track		Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines	Existing lines	Existing lines	Exclusive line for HSR	Exclusive line for HSR	Exclusive line for HSR and existing lines	Exclusive lines for HSR but partially using existing lines.
Separation from existing railways		Separated	Open to existing concourse and platform	Separated	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Separated	Separated	Separated

Source: Compiled by Study Team

9.13.4 Ticketing System for High Speed Railway in India

(1) Existing Ticketing System

Indian Railways issues 21 million ordinary tickets and 1.5 to 2.2 million reserved-seat tickets per day. CONCERT (Country-wide Network of Computerized Enhanced Reservation and Ticketing) is used for issuing reserved-seat tickets*[1)]. Here this existing reservation system is discussed with reference to the above-mentioned layer model in order to consider a desired system for the high speed railway in India. Figure 9.13-3 shows only the layer structure for convenience of reference.

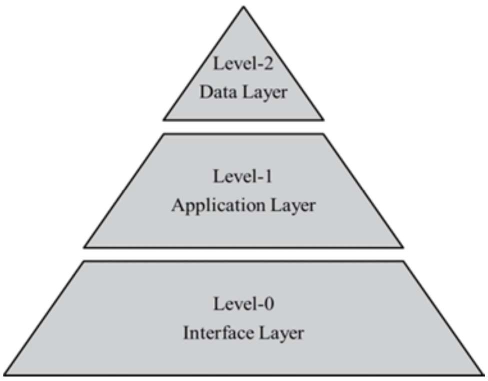


Figure 9.13-3 Ticketing System Structure

Source: Compiled by Study Team

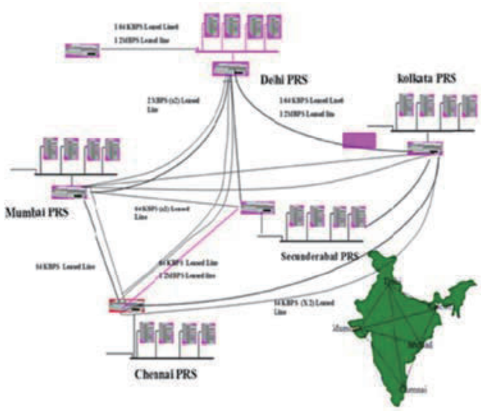
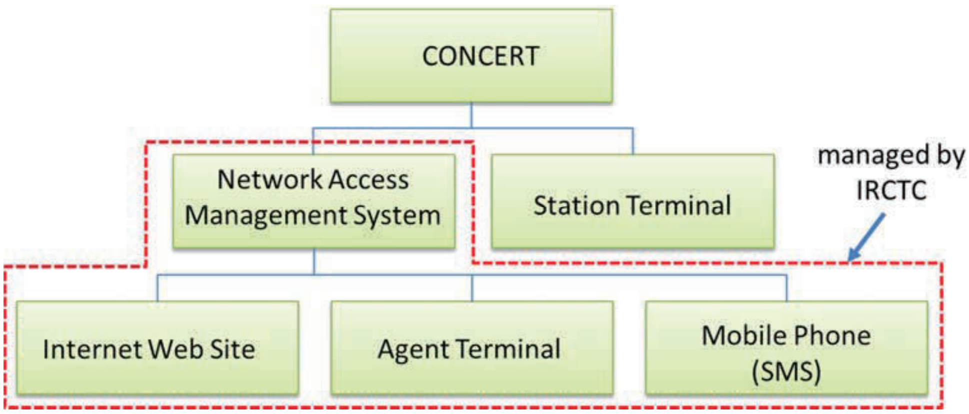


Figure 9.13-3 Indian Railways' Reservation System*[2)]

*1) https://www.services.irctc.co.in/beta_images/sms_booking/sms_ussd.pdf
*2) CONCERT: Journals of Engineering, Computer and Applied Sciences, vol. 2 No. 6,

CONCERT was developed and is managed by CRIS (Center for Railway Information Systems: an organization under Ministry of Railways). CONCERT, one of the world's largest reservation systems, has five data centers across the country, as seen in Figure 9.13-4, for ticket issuing and reservation for any train line.

CONCERT is the core of the reservation system and works on Level 1 and Level 2 of Figure 9.13-3. Level 0 of the figure has a structure as shown in Figure 9.13-5, which provides various ways of booking and buying tickets not only at the station but at agents including post offices, on the Internet, and by mobile phones.



Source: Compiled by Study Team

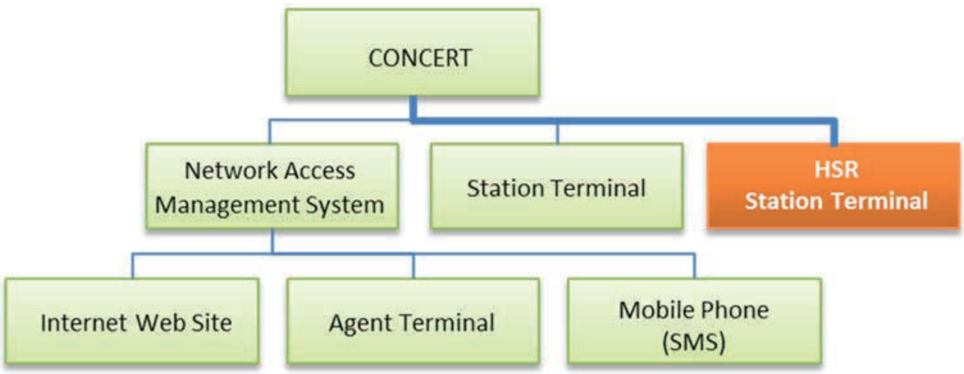
Figure 9.13-4 Structure of Existing Ticket Booking and Issuing System

Passengers can buy ordinary paper tickets at the ticket window, or e-tickets via the Internet. E-tickets can be printed and displayed on mobile terminals. The SMS for buying tickets without Internet connection is also available beginning on June 28, 2013. Passengers, if they have no tools for accessing the Internet, can book tickets at stations, 2,000 agents with terminals nationwide, 270 post offices, 70,000 agents linked to the reservation website of IRCTC (Indian Railway Catering and Tourism Corporation), and via mobile phones. This existing ticketing system, which provides various ways for using services, is very convenient.

(2) Ticketing System Structure for High Speed Railway

The HSR must provide as convenient services as the existing railways. In order to realize it , HSR should utilize the existing system rather than creating a new system. When the existing system is used, reservation and ticket issuing will become possible not only at HSR stations but at existing stations and agents, and via the Internet and mobile phones. Moreover, tickets of both HSR and existing railways can be bought at one site. Connection to the existing railway is planned at four of the twelve HSR stations. The integrated ticketing system enables to issue connection tickets all together, which would improve convenience for users.

The development of the HSR ticketing system by utilizing the existing system is considered as basically possible if an HSR terminal system is connected to CONCERT and HSR reservation-related data, including operating schedules, seating charts and fares, is added to CONCERT.

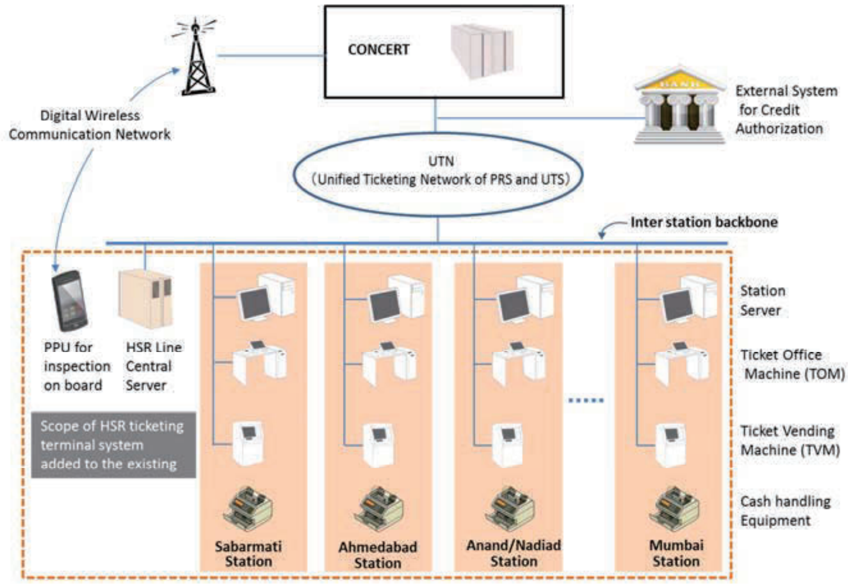


Source: Compiled by Study Team

Figure 9.13-5 Relationship of Entire Ticketing System and HSR System

According to CRIS that manages CONCERT, technical specifications, including API (Application Programming Interface), for devices connected to CONCERT have been available, and their use will make connection to CONCERT possible, as indicated in Figure 9.13-6.

In considering the HSR ticketing system connected to CONCERT, its scope of work to be considered is focused on the terminal system. Figure 9.13-7 shows a terminal system structure to be considered. The dotted part in the figure represents the terminal system. As mentioned below, it includes the PPU used for on-board inspection by the conductor.



Source: Compiled by Study Team

Figure 9.13-6 HSR Terminal System Structure

(3) System Components

1) Tickets

When the existing ticketing system with CONCERT as its core is applied, the same ticket format with that for the existing railways, as shown in Table 9.13-2, can be used for the HSR. The ticket format is common between both HSR and existing railways, therefore the connection ticket can be used throughout both railway routes. It is very convenient for users.

Table 9.13-2 Types of Tickets

Ticket		Issue of Ticket	Method of Payment	Image of Ticket
Paper ticket		Ticket window at Station	Cash	
		Agent	Cash, Credit/Debit card	
		TVM at Station	Prepaid smart card	
E-ticket		Website	Credit/Debit card Withdrawal from bank account Net-money	
	i-ticket	Website Ticket delivery to customer		
	SMS ticket	SMS to mobile phone		

Source: Compiled by Study Team

2) Ticket Issuing

i) Ticket Issuing System: The existing ticketing system being used, HSR tickets can be issued not only at HSR stations, but also at existing railway stations and travel agents, on the website, and via mobile phones, as shown in Table 9.13-3. The table also indicates the number of mobile phone users. Given the fact that PCs can also be used for Internet reservation, the use of the existing issuing system is obviously more beneficial than the development of a new exclusive system.

Table 9.13-3 Number of Sites to Issue Existing Railway Tickets

Site of Ticket Issue	No. of Site
Sales Agent	2,000 agents
Post Office	270 offices
Internet Sales Agent	70,000 agents
3G-mobile phone user	34 million users *)
Other mobile phone	870 million users *)

*) http://wirelesswire.jp/Inside_Out/201309271245.html

Source: Compiled by Study Team

ii) Issuing Equipment at HSR Stations: The issuing system installed at HSR stations is supposed to be primarily composed of machines as listed in Table 9.13-4. These machines will be connected to CONCERT, so technical specifications for connection, data processing, ticket issuing, etc. must comply with the technical specifications drawn up by CRIS, the developer and manager of CONCERT.

Table 9.13-4 Issuing Equipment Installed at Station

Equipment	Function
Ticket office machine (TOM)	Reservation and issue of ticket by operation of station staff.
Ticket vending machine(TVM)	Reservation and issue of ticket by operation of customer.
Station server	Management of station equipment (TOM ,TVM), and processing of data from/to the station equipment.
Cash handling equipment	Counting bank note and coins

Source: Compiled by Study Team

TOMs for the existing railways are installed at ticket windows, as seen in Figure 9.13-8, and CRT displays and dot impact printers are installed as output equipment. As for areas that have no relation to the specifications and requirements for connecting to CONCERT, latest, superior technology should be adopted to reduce electricity consumption, improve performance, and save costs.

For example, though cash payment is common at ticket windows, there seem to be greater needs for payment by credit/debit card among HSR users. To use the TVM currently introduced on a trial basis (Figure 9.13-10), a customer must buy a prepaid smart card in advance. It is also necessary, for improving users' convenience, to make it possible to use the TVM in cash and with the credit/debit card.

Figure 9.13-8 Ticket Issuing Window

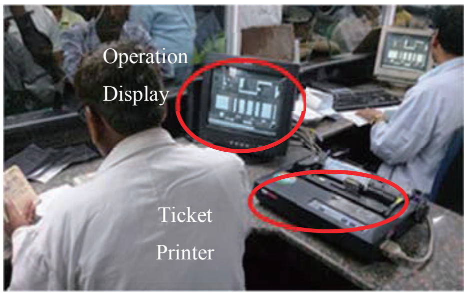


Figure 9.13-7 Equipment at Window

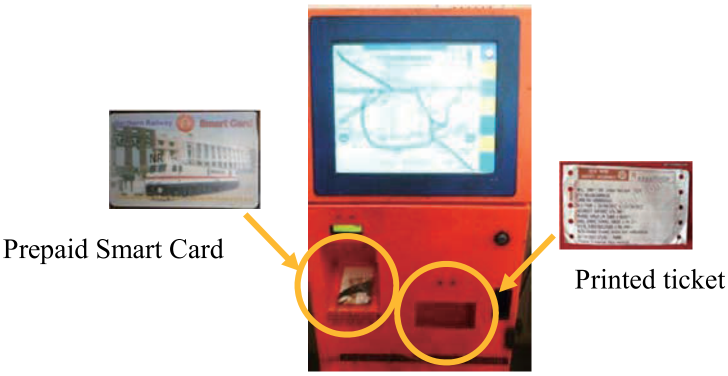


Figure 9.13-8 TVM used for the Existing Railways

3) Ticket Inspection:

There are two ways: i) inspection at the entrance to the concourse and ii) inspection on board.

i) Inspection at the entrance to the concourse: It is estimated that the high speed railway will be used mainly by customers who have chosen aircraft instead of railways before then. And such users are supposed to demand safety and quality services equivalent or exceeding those of air travel. To meet this demand, the HSR must ensure that only HSR ticket holders are allowed to get on board. For this purpose, it is required to separate the HSR concourse from the free concourse and check both security, which is inevitable for HSR as same as for aviation, and tickets at the inspection gate, as seen in Figure 9.13-11. It is difficult to prevent passengers with no HSR tickets from entering HSR platforms unless free access to the concourse is permissible. The train will have ten vehicles when services start in 2023, and the number of vehicles is to be increased to 16 in 2043. In addition, the number of trains running each way during peak hours will also increase from three, four, six to eight per hour. So, though checking tickets before the train door is plausible, this method that requires assigning an enough number of staff members at each station is likely to impose a heavy burden on management.

ii) Inspection on Board: All HSR seats are supposed to need reservation. Passing through the ticket gate means that the reserved seat is secured for the relevant customer. However, as the number of trains running per hour increases as mentioned above, trains arrive at the station one after another at shorter intervals. In such conditions, passengers may get on a train before them without waiting for the designated train to come, and try to find empty seats. Though two or more types of seats, including business class and standard class seats, are planned to be provided, there may be some passengers who take a seat in other class than that designated for them. In order to prevent improper riding, it might be possible to close the platform until the train arrives to allow only holders of reserved-seat tickets for the train to enter. However, when train intervals are short, many passengers must wait outside the concourse. Terminal and other stations used by a large number of people can be so crowded unless they have enough space, which may undermine convenience and safety for users. Moreover, such a method cannot help find passengers who take a seat in other class than that designated for them, or who do not take the right seat reserved for their own. Given these factors, on-board inspection is required.

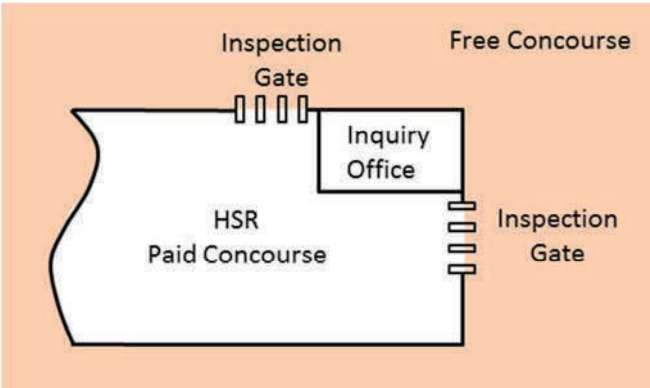


Figure 9.13-9 Inspection at the Entrance to the HSR Concourse

iii) Comparison of inspection methods: Table 9.13-5 shows the summary of what was discussed above. Entrance inspection and on-board inspection are complementary each other, so it is probably desirable to adopt both methods.

Table 9.13-5 Comparison of Inspection Methods

Function of Inspection	Entrance Inspection	On-board Inspection	Entrance and On-board Inspection
Admission of boarding by HSR ticket	Possible	N/A	Possible
Instruction to take designated train	N/A	Possible	Possible
Instruction to take designated class of seat	N/A	Possible	Possible
Instruction to take designated seat	N/A	Possible	Possible

iv) Inspection Equipment

a) Ticket gate: HSR tickets will be issued by use of the existing ticketing system. Their format is the same as that for the existing railways, so HSR tickets are not adaptable to automatic inspection. If the bar code or the 2D QR code is attached to the ticket, it is possible to scan it for automatic ticket inspection. However, the dot impact printer currently used at ticket windows does not have a high resolution enough to print the bar code and the 2D QR code. Even if the ticket is received on the SMS, the low-resolution mobile phone cannot display the code accurately, so it cannot respond to automatic inspection.

Given these conditions, automatic inspection should be considered along with the future renewal of the existing system. Inspection by station clerks is desirable for the meantime.

b) Portable conductor terminal (PPU): Seat reservation is locked when the prescribed time before the departure time of the train is over (Reservation for existing railway seats is possible until thirty minutes before the departure time). Then CONCERT outputs a reserved-seat chart to be used by the conductor for on-board inspection (Figure 9.13-12). The conductor checks tickets against this chart in which passengers' names, reservation numbers, seat locations, etc. are described. The conductor charges an additional fare to the passenger who does not have a proper ticket. What is seen in Figure 9.13-13 is a ticket book for on-board issuing.

The status of seat reservation changes as reservation data is input from other stations after the train leaves the starting station. The HSR train will run about 500 km from the starting station to the terminal in approximately three hours by ordinary service. There will be twelve stations on the route. This means that the train runs between two stations in an average of 16 minutes, including the stoppage time at the station. Therefore, passengers will change in a short time, so the changing information on reservation needs to be delivered to the conductor in the train on a real-time basis. That's why the introduction of PPUs is necessary. The use of the PPU always connected to the ticketing system by digital wireless communication network would make it possible to renew the reserved-seat information before the train reaches the next station. It will also be possible to assign the function of on-board issuing to the PPU. According to CRIS, some existing railways have begun to introduce PPUs, and an infrastructure for the host system has been built. Therefore, the adoption of PPUs for the HSR is also deemed to be possible.

Figure 9.13-11 Reserved-seat Chart for On-board Inspection

Figure 9.13-11 Ticket Book for On-board Issuing

(4) Proposal on the Ticketing System Structure

Based on the above examination, the following proposal on the ticketing system for HSR is submitted from the viewpoint of realizing a system with high investment efficiency and due consideration of cost reduction while placing the highest importance on the safety and convenience of users.

1) System Structure

A ticketing system for HSR is constructed as part of the CONCERT-centered ticketing system. This is because utilization of CONCERT, which is highly functional and time-proven, should be supposed to realize a convenient ticketing system of a lower investment cost than constructing another one for HSRs independently.

2) Ticket

Tickets in the same format applied to the tickets for the existing railways will be used from the two viewpoints of the convenience of connection to the existing railways and the convenience of purchasing. The common format will offer a possibility of purchasing tickets in various existing methods, such as from agent and by mobile phone, and make it possible to issue tickets available for connection as a package. Consequently, users can make connections seamlessly from the existing railway to the HSR and vice versa without bothering to purchase a ticket at every connection station.

3) Ticket Issuing

Taking the above concepts into consideration, a system that can utilize all the existing systems including stations of the HSRs, stations of the existing railways, agents, the Internet and reservation by mobile phone, will be adopted.

4) Ticket Inspection

Paid concourse will constructed separately and ticket inspection gate and security check gate will be constructed at the entrance to ensure high security and service quality desired by users of the HSR. In addition, on-board ticket inspection will be conducted to correct the usage of undesignated train, seat class, and seat. Station staffs will inspect tickets in the initial stage, and in future stage the automation like automatic ticket inspection will be considered from the viewpoint of establishing a comprehensive ticketing system because manual inspection will cause congestion at the gate. However, PPUs will be introduced to reduce the burden of conductors in on-board ticket inspection and the dissatisfaction of users in ticket inspection.

5) Flexibility to the Fare System

There is a probability to introduce a system that sets the fare higher in the busy season for better profitability and offers discount fare in the off season to improve seat availability. The ticketing system should be constructed to cope with various fare systems. Generally, fares are calculated and processed by the Application Layer (Level-1) and Data Layer (Level-2) of the ticketing system. Therefore, in the case that a system is constructed on the basis of the CONCERT system, the requirements can presumably be satisfied by adapting the software of CONCERT to the fare system.

6) Concept of Equipment Specifications

Based on the above mentioned approach, the equipment necessary for ticketing of HSR consists of ticket office machine (TOM), automatic ticketing machines (TVM), Station Servers that manage these pieces of equipment and process necessary data, Line Central Server that collects data from all stations on the HSR line, and PPUs used by conductors for on-board ticket inspection. These pieces of equipment should adopt the technological specifications to make them connect to CONCERT, while other specifications with state of the art functions will be incorporated in the design stage taking the requirements into consideration.

7) Equipment for Education and Training

Equipment for the education and training of staffs will be installed. The equipment will have the same station equipment and PPU used in the practical business. At least two pieces each of station equipment will be prepared to allow education and training for such practical operations as handling ticket issued at other stations. A server with restricted functions of Line Central

Server for education, training and emulating CONCERT will be installed to give staffs satisfactory training opportunities without the anxiety of affecting the system that actually operating.

(5) Technological Requirements for the Ticketing Equipment

The following are the results of examination on the equipment to be installed anew for ticketing of the HSR.

1) Technological specifications

TOM, TVM, and PPU are connected to CONCERT for operation. Therefore, they have to be compatible with the technological specifications necessary for the connection to CONCERT.

2) Requirements of the Station Equipment

(i) TOM (Ticket Office Machine)

- a) The function to handle booking of reserved tickets of the HSR and the existing railways, issuance of various types of tickets such as booked reserved tickets, and refund via the online connection to CONCERT.
- b) The online system function that can manage sales, data of money received and paid, and operation history.
- c) Such functions as the cash box management and ID management that manage the work shift of station staffs.
- d) The access control function that allows only certified staffs to get access.
- e) The function to print tickets. It should have enough resolution to print bar codes and enough resistance to fading for the future.
- f) The function to issue receipts.
- g) The function to accept credit cards and debit cards besides cash.
- h) The function to display information for users.
- i) The voice guidance function for blind users.
- j) The function that provides sings and voice guidance in more than two languages including English and Hindi.
- k) The UPS function that copes with temporary power shutdown.

(ii) TVM (Ticket Vending Machine):

- a) The function to handle booking of reserved tickets of the HSR and those of the existing railways, issuance of various types of tickets such as booked reserved tickets via the online connection to CONCERT.
- b) The online system function that can manage sales, data of money received and paid, and operation history.
- c) The function that allows users to input information necessary for ticket issuing on the operation panel.
- d) The print function to print tickets. It should have enough resolution to print bar codes and enough resistance to fading for the future.
- e) The function to issue receipts.
- f) The function to accept payment by banknote.
- g) The function to accept credit cards and debit cards besides cash.

h) The function to accept payment by non-contact prepaid card (Optional).

i) The function that allows blind users to purchase a ticket using braille keys and the voice guidance function.

j) The function that provides sings and voice guidance in more than two languages including English and Hindi.

k) The UPS function that copes with temporary power shutdown.

l) The access control function that allows only certified staffs to get access for repair and maintenance.

(iii) Station Server

a) The function that tallies ticket issuing data (sales, OD information) coming from ticketing equipment at stations.

b) The function to produce various kinds of reports.

c) The function that monitors the condition of the station ticketing equipment.

d) The function to trades data with Line Central Server and CONCERT.

e) The function that backups data through redundancy.

f) The access control function that allows only certified staffs to get access.

(iv) Cash counting machine:

a) The function to count banknotes.

b) The function to bundle banknotes.

3) Requirements for the Center Equipment

(i) Line Central Server

a) The function that tallies ticket issuing data (sales, OD information) coming from ticketing equipment at all the stations of HSR.

b) The function to produce various kinds of reports.

c) The function that manages the registered machine organization of the ticket equipment at every station.

d) The remote control function that monitors and maintains the condition of all ticketing equipment

(ii) Equipment for education

a) TOM, TVM, Station Server, PPU: They should the same function as the equipment that is really been operated.

b) Emulator: It should focus only on the functions necessary for education and training and allows the emulation of Line Central Server and CONCERT.

4) Requirements for Other Equipment

(i) Portable Processing Unit (PPU)

a) The function that downloads information on booking of reserved seats and ticket issuing via the digital wireless communication network to the CONCERT system.

b) The function to display the seat reservation situation in accordance with train organization.

c) The function to input, record, and display the result of on-board ticket inspection.

d) The function to transmit ticket issuing data to CONCERT.

e) The function that allows ticket issuing on board via the connection to CONCERT.

(6) Examination of the Number of Ticketing Equipment

1) Preconditions for examining the number of ticketing equipment

(i) Calculation is based on the number of passengers of each station and the number of traveling trains examined by the study team.

(ii) The peak rate was calculated using the number of traveling trains at the peak time and that of all day on the condition that all seats are reserved seats: 10%

(iii) Using the information on reserved tickets obtained from the related department of India, the ratio of tickets issued at station vs. ticket issued by the network, and the ratio of tickets issued at TOM and by TVM of all tickets issues at stations are set as shown in Table 9.13-6.

Table 9.13-6 Ratio of Ticket Issuing Method

Year	2023				2053			
Ticket Purchasing	Station			Network	Station			Network
		TOM	TVM			TOM	TVM	
Ratio (%)	40	70	30	60	30	50	50	70

Source: Compiled by Study Team

(iv) Based on the information from the related department of India and results of the field survey, the time to purchase a ticket at TOM or by automatic ticketing machine is set: 1 minute/person

(v) The waiting time in queuing line is set with consideration of the target set by the Delhi Metro Service: 5 minutes at most.

(vi) The minimum number of units is set both for TOM and TVM with consideration of backup in failure: 2 units at least.

2) The number of units to be set a station

Table 9.13-7 shows the number of TOMs and TVMs to be installed at a station. Because users of the Internet will presumably increase more than anticipated, it is advisable to set the number of units to process passengers for a period of 10 years after the inauguration at this moment and set it in accordance with the dynamics of passengers. However, station space that takes the number of passengers in 2053 into consideration is required.

Table 9.13-7 Estimated Number of TOMs and TVMs at Each Station

Station	Initial (Y2023-Y2033)		Future (Y2053)	
	TOM	TVM	TOM	TVM
Sabarmati	2	2	2	2
Ahmedabad	10	4	14	14
Anand/Nadiad	3	2	3	3
Vaodara	3	2	4	4
Bharuch	2	2	2	2
Surat	3	2	4	4
Bilimora	2	2	2	2
Vapi	2	2	2	2
Boisar	2	2	2	2
Virar	2	2	2	2
Thane	2	2	3	3
Mumbai	14	6	20	20
Total	47	30	60	60

Source: Compiled by Study Team

3) The number of units to be installed in the center

(i) Line Central Server: 1 unit

(ii) Equipment for education and training:

a) Emulator: 1 unit

b) TOM: 2 units

c) TVM: 2 units

d) PPU: 2 units

4) Other equipment:

- PPU: 100 units

  The calculation was made on the condition that the number of conductors on board is two (10-vehicle train) and three (16-vehicle train), and the number of trains was considered for the calculation.

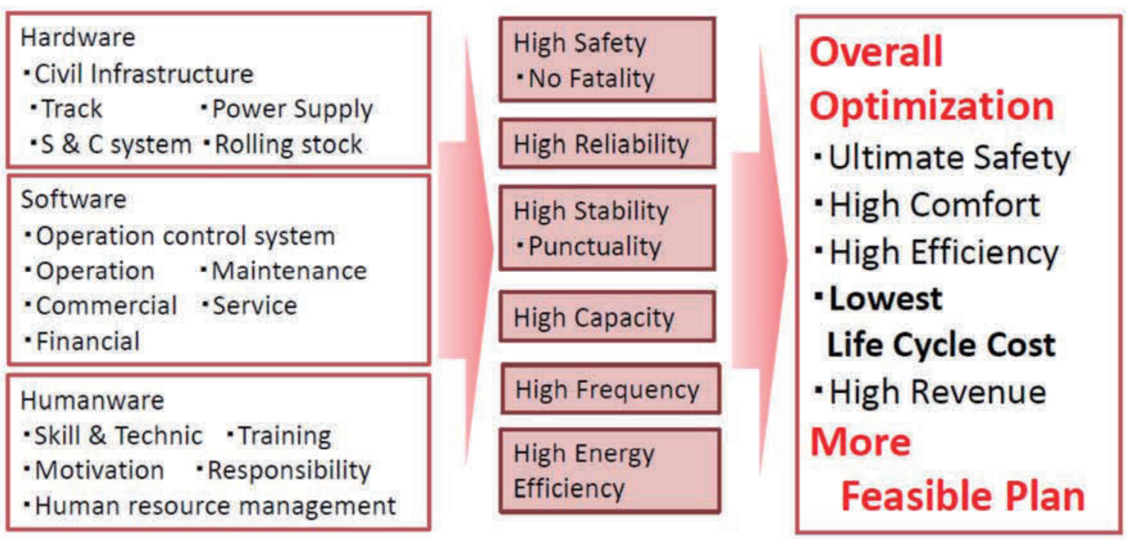
9.14 Comparison between Recommended Systems and Alternatives

9.14.1 System Integration and Total Design Management

(1) Total Design Management

HSR is an integrated system composed of not only hardware systems, such as infrastructure, rolling stock, power supply, signaling and communications, but also software & humanware, such as skills, technics, motivation, responsibility, and so on. Though hardware sub-systems are usually designed and provided by each supplier, hardware, software and humanware affect one another. Therefore system integration is the key to the success of HSR.

Generally, a railway operation company needs to be responsible for all results and issues generated from railway operation. Therefore it needs to manage all concerned suppliers and work with them to develop system best suited for its needs. It is extremely important to pursue total design management aiming at overall optimization, rather than partial optimization from the planning stage of HSR. Figure 9.14-1 shows the concept of Total Design Management.



Source: Study Team

Figure 9.14-1 Total Design Management

Examples of total optimization aspect are total safety system, total efficient system, lowest Life Cycle Cost (LCC) and so on. Safety is the top priority of HSR. Reduction of construction cost is of course important, however regarding a huge and long-life project like HSR, it is more important to evaluate by not just construction cost but by total safety, efficiency or LCC. That is because, even if selection of higher quality system might lead higher construction cost, it could realize higher safety level, stability, efficiency, comfort, and increase passenger revenue, decrease operation and maintenance cost. Higher safety level, higher stability, higher comfort; such as high-grade accommodation and service; could capture more customer satisfaction and confidence, resulting higher revenue. Higher efficiency can contributes to low cost operation, resulting reduction of operation cost and higher competitiveness. As the result it could pay higher construction cost and contribute to higher profit and more feasible plan. System integration aiming at overall optimization is exactly what Japanese Shinkansen system has realized, and Shinkansen system has been improving through adopting state of the art technologies from the view point of them.

(2) Shinkansen's way

The Shinkansen system is based on the concept of eliminating collisions by using grade-separated dedicated track and an advanced train protection system known as ATC. In addition, unauthorized persons are prohibited from entering the track right-of-way by law. These key factors together with high-reliable protection systems against natural disasters have enabled Shinkansen to continue its record of "zero" passenger fatalities since the start of revenue service over 50 years ago.
The introduction of EMU, a lightweight wide-body rolling stock, has provided large passenger capacity and is robust in the event of a failure. With the EMU's light axel load and air-tight body structure, it also contributes to compact infrastructure, lesser-loads, smaller cross sectional tunnel and so on, resulting reduction of infrastructure cost.
Moreover EMU is also capable fast acceleration and deceleration. In conjunction with this, these following, such as 1) Unification of train operation, 2) Centralized operation control system, and 3) Separation of operation & maintenance has ensured high-density stable operation. Therefore the most operation efficiency is realized. Besides them, excellent operation and maintenance system, technic & skills realized lowest life cycle cost.
Recently after the success of Shinkansen, dedicated-line, EMU or other excellent features Shinkansen proved, have been adopted in many countries, but Shinkansen still has great advantages owing to its greater experience and accumulation of knowhow.

9.14.2 Comparison from the View Point of Cost and Technical Aspect

(1) Civil infrastructure

As a result of comparing the HSR structure of Japan, France, China and other countries, study team recommends the dimensions of civil and track and structures for Mumbai-Ahmedabad HSR project as table 9.14-1. Compared to alternatives of the standard of France or China, recommended dimensions are cost effective. For example, 80m^2 of tunnel cross section is 30% cost effective than 100m^2 cross section tunnel in France or China. Ballastless track costs high at the capital cost, but LCC of ballastless track would be lower than ballasted track in 10 years in Japanese Shinkansen case.

(2) E & M system selection

As mentioned above, HSR is an integrated system therefore it means little to compare each sub-system on one's own separately. Moreover such a sub-system is more or less customized according to its requirement, and generally its price, which is affected by its current sales policy, is not disclosed. Therefore in this section, comparison between recommended systems and alternatives will be roughly described regarding only main sub-systems, Power supply, Signaling & communication, and rolling stock, just for information.

Recommended systems and those alternatives are compared in the table 9.14-2. It is not necessarily the case that the recommendations are lower than the alternatives in construction cost aspect. However the alternatives have insufficient performance or ability for high safety, stability, and high density H.S train operation expected in this project, or inferior to recommendations in aspect of system integration and overall optimization.

Table 9.14-1 Comparison of Civil & Track Structures

Recommendation	Alternative	Alternative's Procurement Cost	Technical Aspect
• Maximum Axle Load (design) 17(t)	Japan: 16-17t France: 17t China: 20t	Japan: Low-Same France: Same China: High	17t is enough for passenger dedicated line.
• Distance between Track Center 4.5 m	Japan: 4.2-4.3m France: 4.2-4.8m China: 5.0 m	Japan: Low- Same France: Low-High China: High	Distance between Track Centers affects land acquisition and structure volume.
• Formation Width 11.5 m	Japan: 10.9- 11.7m France: 13.6-14.2m China: 13.4-13.8 m	France (14.0m) : High (+ 3.6%) (viaduct)	Formation width affects land acquisition and structure volume.
• Cross Section of Double-Track Tunnel 80 m^2	Japan: 62.8-63.5 m^2 France: 71-100 m^2 China: 90-100 m^2	France ,China (100m^2) : High (+ 30%)	The tunnel cross section affects the cost.
• Track Structure Ballastless	Ballasted	Low in Initial Cost High in LCC	Ballasted track will cost higher in 10 years* in view of LCC * Case of Shinkansen in Japan

Source JICA Study Team

Table 9.14-2 Comparison of Sub-Systems, Recommendation and Alternatives

Recommendation	Alternative	Alternative's Procurement Cost	Technical Aspect (Disadvantages of Alternative)
Power Supply system			
• Single Phase AC 2X25 kV	None	-	-
• Transformer/ Scott connection	V-connection	Almost same	• Higher unbalance rate
• OHC/ Compound Catenary	Simple Catenary	Low	• Inadequate for High speed & High density operation due to current restriction
	Y-Catenary(SC with Stich wire)	Almost same	• More difficult for maintenance
• Section System/ Change over switch	Neutral Section	Low	• Unsuitable for emergency stop system at earthquake • Operation speed decreases at neutral section
Signaling & Communication System			
• Signaling/ Digital-ATC	ETCS-Level2	Almost same	• GSM-R's frequency band is insufficient • Inferior in reliability • Track circuit system is most reliable
• Train Radio System/ LCX	GSM-R/ TETRA	Low	• Data rate is less and insufficient to highly advanced Information
Rolling stock			
• EMU	Loco	Cost per Train-set is almost same, however Total Procurement cost is High	• Inferior in Passenger Capacity or other functions such as traction performance, energy efficiency
• Wide Body	Standard		• Inferior in Passenger Capacity, resulting higher cost
• Non-Articulated	Articulated		• Inferior in Passenger Capacity, resulting Higher cost

Source JICA Study Team

9.15 Summary of Workshop for HSR Subsystem

For the purpose of deeply understanding for Indian Participant and reflecting for the ***Interim Report 2***, JICA study team held the work shop concerning sub-system, which are Rolling stock, power-supply, Signalling and Telecommunication, OCC, etc., as follows.

9.15.1 Date, Time, Place and Number of Participants

-Date and Time: 8th September, 2014 11:00AM-17:30PM
-Place: CSOI Conference Room, Vinay Marg, New Delhi
-Total Number of Participants: MOR, RDSO and JICA officer 29 people

9.15.2 Program

(1) Introduction and Main Characteristic of HSR and Operation Plan
(2) Rolling stock plan
(3) Maintenance Equipment for Rolling stoke
(4) Power Supply System
(5) Signalling and Telecommunication
(6) Working of Operation Control Center

9.15.3 Output and Effect of Workshop

-Workshop started and closed on time schedule. At first Japanese Experts explained their presentation for each specialized field, after then Indian participants gave some questions.
-Questions, which included detail and technical matters, were very helpful and show the height of the interest of the Indian side. Each proposal of the Japanese side were almost accepted positive and favorably. We were able to succeed the Workshop with plenty of Indian side cooperation.-These results will be summarized and reflected in the Interim Report 2 until this November.

Figure 9.15-1 Presentation by Japanese Expert

Figure 9.15-2 Closing Remark by Mr. Mathur, Evaluator on staudy Team