

Fallback Systems, Methods, Procedures and Resilience in Train Operation over Indian Railways

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SUMMARY

Outages and Failures in any system comprising a large number of components and sub systems can be reduced to a reasonable level; however, cannot be eliminated beyond a certain level as its achievement shall be cost prohibitive. Therefore, fallback systems, methods and procedures are the essential features to improve the availability of a dynamic system during failure of one or more components or sub systems, minimising the human intervention and thus proving the resilience of the system.

A railway system constitutes three sub systems, Plant & Machinery (Infrastructure), People to operate & maintain and Procedures to deliver the train operation services. Resilience in train operation depends on the resilience of these three sub systems and Railway systems all over the world including Indian Railways provides for such Fallback systems in place to deliver the satisfactory transportation services at a reasonable cost but with reasonable risk, which is tolerable.

This paper intends to examine all such systems in place in its infrastructure, people, process and procedures over the Indian Railways, their contribution towards making the train transportation resilient and associated risks available in the system.

1 INTRODUCTION

Indian Railways (IR) is the fourth largest railway network in the world meeting the consistently growing passengers and freight traffic of 22.54 million and 3.18 million tonnes per day respectively to meet the growing transportation need of the fastest growing Asian economy and its mammoth population. United Nations World Economic Situation and Prospects (WESP) have projected the growth of Indian economy at 7.6 percent in 2018-19. As per the Central Statistical Office (CSO) of India, real GDP growth of the Indian economy has been 6.5 percent in 2017-18 and averaged 7.4 percent from 2014-15 to 2017-18, which is the highest among the major economies of the world. On Purchasing Power Parity (PPP) basis, Indian economy is already the third largest in the world. The growth in Indian economy during the last five years is depicted in the table 1.

Economic Growth Parameter	2014-15	2015-16	2016-17	2017-18
GDP Growth at constant Price (%)	7.4	8.2	7.1	6.7
GVA Growth at Basic Price (%)	7.2	8.1	7.1	6.5

Table 1: Indian Economic Growth

GDP: Gross Domestic Product; GVA: Gross Value Addition.

Source: Indian Railway Year Book 2017-18

To meet the requirements of a consistently growing Indian economy and population, all modes of the transport, are showing positive expansion year after year; however, the role of railways in transportation of bulk commodities and common public and the work force is significant. This transportation requirement is being fulfilled by the operation of more than 20,000 passenger carrying and 9,200 freight trains in 24 hours of any day of the year. A snapshot of the growth of passenger and freight traffic during the last five years is shown in the table 2 below.

Year	Number of Passengers originating (in millions)	Annual Growth Rate (in percent)	Freight Traffic (in million tonnes)	Annual Growth Rate (in percent)
2013-14	8397	(-) 0.28	1058.81	4.40
2014-15	8224	(-) 2.06	1101.09	3.99
2015-16	8107	0.11	1108.62	0.68
2016-17	8116	0.11	1110.95	0.21
2017-18	8286	0.21	1584.1	4.83

Table 2: Passenger and Freight traffic growth in last five years

To enable the mobility of ever growing passenger and freight traffic with resilience and no capacity constraint, Indian railways is expanding and strengthening its network infrastructure with addition of new 2nd, 3rd or 4th lines along the existing track, electrification of lines, introduction of modern signalling and telecommunication systems, rolling stocks and locomotives. Many fold increase in the capital expenditure for these expansion are indicated in the table 3 below.

Year	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Capital Expenditure (in million Rs.)	1006.00	557.39	1101.09	1108.62	1511.1	1584.1

Table 3: IR Capital Expenditure Trend

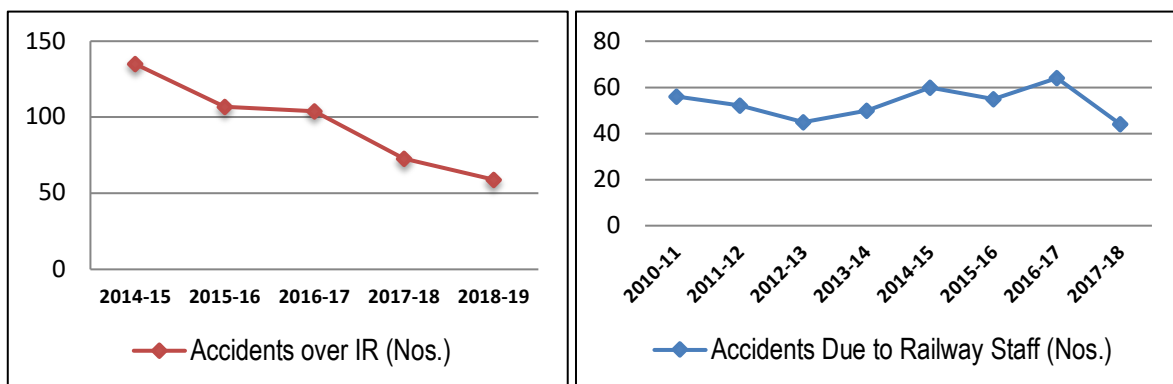
Source: IR Year Book 2017-18

2 CASE FOR RESILIENCE

The growing network of rail infrastructure involves the expansion in the Track, Rolling stock, Motive Power, Overhead Electrical Traction, Power Supply, Signalling and Telecommunication system constituting the infrastructure and 1.3 million workforce involved in operation and maintenance and enabling the running of the above mentioned huge number of trains at optimum operational efficiency and safety. Expansion in the infrastructure brings the vulnerability in the safety performance of the IR system, due to involvement of huge workforce in the operation and maintenance of the infrastructure and construction activities in the existing station yards. Any outage in any one of the above sub systems of infrastructure and slippages by human element of the workforce not only affects the availability of Train Operation System and Safety but affects the society and economy at large in terms of lost man hours. Effectiveness of Fallback systems in place, which reduces the dependence on human, is reflected in the improving safety performance of the IR in general and accidents due to failure of railway staff in particular in spite of expanding network and infrastructure, as per the data compiled in table 4A and 4B below.

Year	Collisions (Nos.)	Derailments (Nos.)	Level Crossing Dashing (Nos.)	Fire (Nos.)	Misc. (Nos.)	Total (Nos.)
2014-15	5	63	56	6	5	135
2015-16	3	65	35	0	4	107
2016-17	5	78	20	1	-	104
2017-18	3	54	13	3	-	73
2018-19	0	46	6	6	1	59

Table 4A: Safety Performance of Indian Railways



Year	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Accidents (Nos.)	56	52	45	50	60	55	64	44

Table 4B: Accidents due to Failure of Railway Staff over Indian Railways

This paper brings out the glimpses of various fall back systems, methods and procedures in place over the Indian Railways, designed, provided and maintained in all the sub systems of infrastructure, operating procedures as well as additional deployment of humans to achieve the optimum level of efficiency in the train operation, reduce the impacts of outages and thus provides the necessary resilience in the system. .

3 INFRASTRUCTURE: FALLBACK SYSTEMS

In a railway system, Infrastructure broadly constitutes Tracks, Bridges, Signalling and Telecommunication, Traction Power Supply, Locomotives, Rolling Stocks, etc that provides for the mobility of trains with predetermined axle load and speed. Features of Fallback systems in place in the above infrastructure sub systems, enabling the mobility of trains during the failure of one or more sub system or deterioration in their parameters are described in the following paragraphs.

3.1 Track

The Speed and Axle load potential of every section of the railway route depends upon the track structure, i.e. weight of rail, length of welded rail panels, sleeper density, ballast cushion and condition of bridges. However, the movement of trains at reduced speed and axle load is permitted during the deteriorated parameters or sub optimum condition of the various components of the track and bridges.

3.1.1 Rails

Rails are the most critical and important component and lifeline of any railway track structure. Therefore, they are not only passed through a rigorous test during manufacturing but their condition is monitored at a predefined schedule as prescribed in the Indian Railways Permanent Way Manual (IRPWM) and Manual for Ultrasonic Testing of Rails and Welds. Indian Railways uses Ultrasonic testing of rails and its welds by specially trained and skilled staff for monitoring of flaws or defects in the rails and welds. For this purpose, organisations with required instrumentation are in place to ensure the testing of entire track length at the specified periodicity. Often, immediate replacement of rail or welds detected with flaw is not possible; therefore, train movement is allowed on such tracks with special precautions and restricted speed to avoid total disruption of services and provide resilience within the system. Such defect conditions, corrective action and permissible speed before the corrective action are as follows:

3.1.1.1 Rails and Weld Defect Classification

Manual for Ultrasonic Testing of Rails and Welds of IR lists 11 and 2 different types of rail and weld defects respectively, out of which 7 different types of Rail defects and both Weld defects can be easily detected by Ultrasonic testing. To enable the computerized statistical data analysis, Indian Railways has adopted the UIC system of coding for reporting rail failures, which is able to describe the rail and weld failures completely. Depending on the strength of the ultrasonic signal, rail and weld defects are broadly classified as follows:

Sl. No.	Nature of Defect	Classification
1	Any horizontal defect in head web or foot of length equal to distance...	IMR
2	Any horizontal defect connecting both bolt holes	IMR
3	Any defect originating from bolt holes and progressing at an angle towards head-web junction or web-foot junction.	IMR
4	Any horizontal defect progressing at an angle in vertical plane in the rail at the following locations in the track: (i) In tunnel & on tunnel approaches (100m either side) (ii) On major bridges & bridge approaches (100m either side) (iii) In the vicinity of holes near the weld	IMR

Sl. No.	Nature of Defect	Classification
5	Any horizontal defect progressing at an angle in vertical plane in the rail at track locations other than above.	IMR
	(i) No back echo with flaw echo for horizontal length > 20mm (ii) No back echo with or without shifting flaw echo for horizontal length < 20 mm	OBS
6	Vertical longitudinal split (piping)	IMR
7	Any transverse defect in the rail head at the following locations in the track:	IMR
	(i) In tunnel & on tunnel approaches (100m either side)	
	(ii) On major bridges & bridge approaches (100m either side) (iii) In the vicinity of holes near the weld	
8	Any transverse defect in the rail head at track locations other than above	IMR/ OBS

IMR: Immediate Removal required; OBS: To be kept under Observation

Similar classification exists for Welds also as follows: however, indicated as DFOW and DFWR.

- a. A welded joint showing flaw echo of 40% vertical height or more and up to 60% is to be declared as DFOW.
- b. A welded joint showing flaw echo of more than 60% vertical height is to be declared as DFWR.

3.1.1.2 Action after Detection of Defects:

Following action is required to be taken in respect of defective rails & welds to continue the use of track although in a restricted manner for continued mobility:

S. No.	Classification	Marking	Action to be taken	Interim action
1.	IMR IMRW	Three cross with red paint on both faces of web	The flawed portion shall be replaced by a sound tested rail piece of not less than 5.5m length (in case of fish plated track)	1. USFD Engineer shall impose speed restriction of 30 Kmph or stricter immediately and to be continued till flawed rail/weld is replaced. 2. Flaw location shall be provided with clamped joggled fish plate within 24 hrs.
	DFWR	Two cross with red paint on both faces of weld	& 4m (in case of welded track) within 3 days of detection.	
2.	OBS OBSW	One cross with red paint on both faces of web	Rail/ Weld shall be provided with clamped joggled fish plate within 3 days.	USFD Engineer shall advise within 24 hrs about the flaw location for the Keyman to watch during daily patrolling till it is joggled fish plated.
	DFWO	One circle with red paint on both side of weld.	USFD Engineer to specifically record the observations of the location in his register in subsequent rounds of testing.	



Figure 1: Rail Flaw Protected with Clamped Joggle Fish Plate

3.1.2 Bridges

Bridges are another component of railway track formation having serious speed, axle load and safety implications. Generally, bridges are designed for the same axle load and speed; however, in the course of use bridges may show physical signs of deterioration of its physical condition due to aging, fatigue and hydrological factors etc. and classified as distressed bridge. Such bridges require rehabilitation through special repairs, strengthening or rebuilding and special precautions, speed restrictions and other measures until their rehabilitation is completed.

3.1.2.1 Bridge Defects Classification

Classification of distressed bridges:

Category-I: Those requiring rehabilitation to be done immediately, say within a year's time.

Category-II: Those requiring to be kept under observation and to be taken up for rehabilitation on a programmed basis.

To prevent the disruption of traffic through the bridge, speed restrictions up to maximum of 15 kmph is imposed for distressed bridges on Group I and 25 kmph to 50 kmph for distressed bridges in Group-II with increased frequency of inspections, which bring resilience in the system. The Groups are defined as under:

Group I: Signs of distress are Settlement of foundations, Tilted piers and abutments, Deep scour around piers/ abutments, Shaken/ displaced/ cracked bed blocks, Cracks or any other distress in bearings, Wide cracks in abutments/ piers, Diagonal cracks in arches, Transverse cracks in arches, Distortion of arch, Displacement of brick/ stone from arch ring, Crushing of masonry, Progressive loss in camber of Prestressed concrete/ steel girders, Wide cracks in Reinforced Cement Concrete/ Prestressed concrete members, Cracks/ heavy corrosion in load bearing members of steel girders, Weak/ corroded/ cracked piles particularly cast iron screw piles and Snapping of rivets.

Group II: Cracks in return walls/ wing walls, Slight tilting/ bulging of abutments, Leaning/ bulging of masonry in return walls/ wing walls, Perceivable deterioration of stone/ brick masonry, Wide longitudinal cracks in arches, abutments and piers, Cracks/ lean/ bulge in parapet walls of an arch, Bulging or separation of spandrel from arch barrel, Spalling of concrete in beams and slabs, Loose rivets above 20% at any joint, Observations of any excessive vibration in part of the bridge structure.

To monitor the rehabilitation/ corrective works on the distressed bridges and restore the designed speed potential, each divisional office of a zonal railway is required to maintain the details of the distressed bridges as per the standard Proforma and the list is reviewed at the end of every year. During rehabilitation works also, traffic is not blocked but allowed at restricted speed as prescribed in IRBM. Once the rehabilitation of a bridge is completed, it is deleted from the list. Completion of such bridge rehabilitation works and expenditure on this over IR during the last five years is presented in the following table.

Year	Rehabilitation of Bridges Completed (Nos.)	Expenditure on Rehabilitation (in million INR)
2013 - 14	591	390
2014 – 15	620	441
2015 – 16	670	520
2016 – 17	750	495
2017 – 18	800	453

Table 5: Bridge Rehabilitation works & Expenditure

In addition to above, a total of 12650 railway bridges were rehabilitated/ rebuilt under the Special Railway Safety Fund (SRSF) during 2001-02 to 2010-11. This exercise was undertaken with a view to clear the backlog of rehabilitation/ replacement of railway bridges in Indian Railway.

3.1.3 Track Formation and Ballast

Bad formations lead to the frequent disturbance in cross level of the track causing twist and parasitic movement of the rolling stock and affecting the speed potential of the track and passenger comfort. Such disturbances require imposition of speed restrictions to avoid the complete interruption to railway traffic. Similarly, bank slips and soil erosion of cess also require speed restrictions until the corrective actions are taken.



Figure 2: Calling on Signal

A standard track with 60 Kg Rail and PSC sleeper density of M+7 and clear ballast cushion of 250 mm with full compliments of track fittings provides speed potential of 130 kmph. During the service life of the track, ballast gets crushed, which requires recoupmnt of ballast from time to time. However, delay in recoupmnt of deficient clear ballast make the track components, viz. PSC sleepers and rails prone to cracks and fractures respectively. In order to avoid these incidences, suitable speed restriction is imposed to continue the traffic with degraded speed potential. Such speed restrictions are decided by the competent track engineers as per the track parameter measurements and their experience. These measures mandated in the IRPWM provide resilience in train operation in the event of deterioration in track parameters due to inadequate clean ballast cushion and bad formation etc. Similarly, during heavy downpour when water starts flowing over the danger level of any bridge, traffic is allowed at a limited speed of 15 kmph and

totally suspended during flowing of water over the bridge.

3.2 Signalling

Signalling systems provided over the IR contribute to the capacity enhancement of the fixed infrastructure like track, OHE and productivity of rolling stocks, locomotives and personnel involved in the train operation by incorporating the flexibility in the use of infrastructure and eliminating the human element from the train operation to a large extent. IR Signalling systems is designed to the Safety Integrity Level (SIL – 4) as per European standard for Railway Application RAMS EN 50126 and fail safe principles and any single failure in the signalling system does not allow unsafe conditions.

3.2.1 Degraded Mode of Signalling

The provisions of signalling at a station yard and block working between the two stations eliminates the human element in the train operation, reception and dispatch from/ to a station and reduces the chances of human error by automating the setting of routes, detection of track occupation and signalling the trains. The failure of any sub-system or component of signalling or block working disrupts the train operation in normal mode and speed. Therefore, the provision of degraded mode in the signalling system like Calling On Signals, Emergency Electrical Operation of Points from station master control panel or manual operation with the help of Crank Handles facilitate the train operation in a restricted mode with least involvement of human element. In addition, degraded mode of operation is also in place, involving the human element with or without means of communication to continue the train operation although with restrictions.

Involvement of human element (Operator as well as Maintainer) in the event of a single failure also increases the probability of human error and thereby increases the risk of unsafe condition. Therefore, standby and degraded

mode of operations are inbuilt within the signalling system and well defined train operating procedures during failures are included in the Rule Books, viz. General & Subsidiary Rules, Block Working Manual, Operating Manual etc. A few important features incorporated in the Signalling system and operating procedures to enable the degraded mode of operation without compromising the safety are as follows:

Sl. No.	Failure Mode	Degraded Mode Methods and Restrictions, if any.
1	Failure of Home Signal for reception of trains at a station yard.	Calling On signal. Trains are stop dead at the Home signal and then allowed at 15 kmph.
2	Failure of Train detection system of berthing track in the station yard.	Calling On signal. Trains are stop dead at the Home signal and then allowed at 15 kmph.
3	Failure of Point Zone Track Circuit	Emergency Operation of Point from control panel after confirming no obstructions in the point zone.
4	Broken Lifting Barrier of Level Crossing Gates	Sliding Boom with key locking with full functionality

Table 6: Degraded Modes in the Signalling System

3.2.2 Degraded Mode Procedures

Sl. No	Failure Mode	Degraded Mode Procedures and Restrictions, if any.
1	Defective Block Instrument and communication	Use of Paper Line Clear after exchange of Private Numbers by the both ends Station Masters through alternative means of communications. No restrictions after handing over of authority to pass departure signal at danger and paper line clear.
2	Defective Last Vehicle Checking Device	Physical verification of the complete arrival of last vehicle i.e. full train before closing the block section and use of Paper Line Clear as in Sl. No. 1 above.
3	Defective Intermediate Block Signals (IBS)	Loco Pilot (LP) to Stop at the IBS and wait for 5 minutes and proceed cautiously if unable to communicate with the section controlling Station Master. Speed of 15 Kmph during day and 8 Kmph during inadequate visibility of line ahead.
4	Defective or Automatic Stop Signal at ON (RED)	Train to stop in rear of the Automatic signal, LP to wait for 1 minute by day and 2 minutes by night and then proceed. Proceed to the next stop signal exercising great caution so as to stop short of any obstruction.
5	Defective Series of Automatic signals	Station Master to suspend the automatic signalling and work the block section with Paper Line Clear after exchange of Private Numbers by the both ends Station Masters. First train to run at maximum speed of 25 Kmph and subsequent trains at normal speed.

Sl. No	Failure Mode	Degraded Mode Procedures and Restrictions, if any.
6	Total Failure of Telecommunication between two stations.	Exchange of message between two Station Masters with the help of railway staff, Grant of conditional Line Clear using Paper Line Clear ticket in case of Single Line or Authority to proceed without Line Clear in Double Line and authority to pass signals at ON. First Train to clear the block section at 25 kmph over the straight and 10 Kmph where view ahead is not clear and subsequent trains at normal speed after an interval of 30 minutes.
7	Obstruction of one line in double line section when communication between the stations is available.	Use of Block Ticket supported with exchange of Private Numbers by the both ends Station Masters. First Train to clear the block section at 25 kmph and subsequent trains at normal speed
8	Lifting Barriers of LC Gate open and Gateman missing.	LP to stop short of the gate. Lower the lifting barrier and close the road traffic, pass LC Gate and stop for the Guard to open the lifting barrier. Stop – Start – Stop – Start.

Table 7: Degraded Mode Procedures during the failures in Signalling System

3.2.3 Forms For Use During Failure of Signalling and Block Working

To facilitate operations in above mentioned failure modes, operating procedures are well defined in the Indian Railway General and Subsidiary Rules, 2005. This rule book provides the duties of Station Masters, Loco Pilots and Guards during degraded mode of operation. It includes standard forms to be used during different conditions of failure for unambiguous understanding by the Railway staff and reduce the risk in train operation to As Low As Reasonable Practicable (ALARP). For clarity and understanding, a few Standard Forms for use during such operations involving a human element are listed below:

Sl. No.	Form No.	Subject Description
1	T/369/1	Advance Authority to pass defective signals
2	T/ 369 (3b)	Authority to pass signals in 'On' or defective position
3	T/ 409	Caution Order
4	T/ 509	Authority to receive a train on an obstructed line.
5	T/511	Authority to start form a Non signalled line
6	T/ A 602	Authority to proceed for relief engine / Train into an occupied Block Section.
7	T/ B 602	Authority for opening communication during Total interruption of communication on single line.
8	T/ C 602	Authority for working of Trains during Total interruption of communication on Double line.
9	T/ D 602	Authority for Temporary Single Line Working on Double Line Section.
10	T/E 602	Line clear Inquiry Message asking Line Clear for Despatch of trains during Total Failure of Communication on Single line Section
11	T/F 602	Conditional Line Clear Message
12	T/ G 602	Conditional line clear ticket (Up)
13	T/ H 602	Conditional line clear ticket (Dn)
14	T/I 602	Message on Restoration of Communication

Sl. No.	Form No.	Subject Description
15	T/ 609	Written permission by Guard to Driver when the engine and a portion of a train is allowed to proceed to next station from Mid-section.
16	T/ A 912	Authority to pass Automatic / Semi Automatic / Manually operated Gate stop Signals.
17	T/B 912	Authority to proceed without line clear on Automatic Block Signalling Territory
18	T/ C 912	Authority to proceed for Relief Engine / Train into Automatic Block Signalling section.
19	T/ D 912	Authority to proceed on Automatic Block System during Prolonged Failure of Signals.
20	T 1410	Train Intact Arrival Register.
21	T/A 1425	Line Clear Enquiry Message (Outward/ Inward)
22	T/B 1425	Line Clear Reply Message (Outward/ Inward)
23	T/ C 1425	Paper Line Clear Ticket (UP)
24	T/ D 1425	Paper Line Clear Ticket (DN)

3.2.4 Degraded Mode of Train Operation Communication System

To facilitate the operation of Block Instruments between two stations for block working and effective control of train operation by divisional controls, block communication and control communication is made available with the help of underground Quad Telecom cables and Optical Fibre cable based communication system. Generally, these communications are not available in ring form; however, a single failure in transmission media is taken care of by using route diversity and alternate telecommunication systems, viz. Station to Station Fixed Telephones, Railway Telephones, Public Telephones, Control Telephones, VHF sets. A priority in the use of these alternative means of communication for train operation along with protection measures is well defined in the Indian Railways General and Subsidiary Rules to ensure continued train operation during the failure of one of the means of communication and thus enabling the resilience in train operation.

3.3 Overhead Electric Equipments

Overhead Electric Equipment (OHE) system provides power to the electric locomotives for operation and is fixed infrastructure. Although a breakdown in the OHE system disrupts the power supply to locomotives causing disruption in the operation yet during certain failure conditions, viz. failure of complete Traction Sub Stations (TSS) or a transformer at TSS, OHE failure of a particular section and siding, methods for continued operation in degraded mode are in place without compromising the equipment and human safety and tabulated below:

Sl. No.	Failure Mode	Degraded Mode Methods
1	TSS failed	Feed extension from healthy TSS through Sectioning Post. Less number of trains allowed in the affected section.
2	One Transformer at TSS failed	Stand by Transformer takes care of Load.
3	Feeder Protection Relay not operated on OHE fault	Either Delta-I Relay or 25 KV Transformer protections operate.
4	Pantograph strips bridges the live & dead zone at Section Insulator	Pantograph flash over relay operates and tripping protected.
5.	OHE of a Siding (Private or Railway) failed.	Siding OHE is isolated through Circuit Breaker at TSS maintaining the main line OHE in healthy condition.

Table 8: Failure Modes & Degraded mode methods in OHE systems

3.3.1 Sub Sectioning and Paralleling Posts

OHE is divided into sub-section between a Traction Sub Station (TSS) and adjacent Neutral Section for isolating the faulty section, repair and maintenance. These switching stations are called Sub-Sectioning and Paralleling

Posts (SSP). OHE of various tracks in multiple line sections are also paralleled at the SSP to reduce the voltage drop. During an emergency when the TSS is out of order, feed from an adjacent TSS of either side are extended up to the failed TSS by closing interrupters at Switching and Paralleling Posts (SP). SP is a switching station at the neutral section.

The above mentioned arrangements take care of limited failure conditions by the use of a standby sub-system to prevent the total disruption of rail traffic. However, such degraded mode of operation is not allowed to continue as further failure in a sub-system may cause total disruption to the traffic.

3.4 Traction System

Both Diesel as well as 25 kV AC Electric traction is in use over the IR. Although an ambitious objective of achieving electrification of the entire 68000 Route Km IR network is in place yet retention of diesel traction is essentially required to maintain the resilience in train operation during failure of OHE systems during storms and inclement weather, electric locomotives disabling, shunting in yards and for relief operations during accidents. To date, 7 different class of diesel and 5 different classes of electric locomotives are mostly in use over IR with speed potential varying from 100 to 160 Km/h. In order to maintain the locomotives fit for safe and full capacity operation, the concept of Homing Loco Shed responsible for their inspection and maintenance as per schedules below is in place for both diesel and electric locomotives.

Sl. No.	Maintenance and Overhauling Schedules	Locomotive Class				
		WAP4	WAP5	WAP7	WAG5	WAG9
1	Trip Inspection	4500 kms or 1 trip	4500 kms or 1 trip	4500 kms or 1 trip	20 days	45 days
	Time Reqd.	2 hrs	2 hrs	2 hrs	2 hrs	4 hrs
2	IA	60 days	90 days	90 days	60 ± 3 days	90 days
	Time Reqd.	4 hrs	4 hrs	4 hrs	4 hrs	4 hrs
3	IB	-	180 days	180 days	120± 3 days	180 days
	Time Reqd.	-	6 hrs	6 hrs	6 hrs	6 hrs
4	IC	120 days	270 days	270 days	180± 3 days	270 days
	Time Reqd.	8 hours	8 hrs	8 hrs	8 hrs	8 hrs
5	AOH/ TOH	18 months ±15 days	18 months	27 months	24 months ±15 days	24 months
	Time Reqd.	6 days	6 days	6 days	6 days	6 days
6	IOH	36 ± 1 month or 6 lakhs kms	4 ½ years ± 6 months or 12 lakh kms	4 years ± 6 months or 12 lakh kms	72 ± 1 month or 6 lakhs kms	6 years ± 6 months or 12 lakh kms
	Time Reqd.	9 days	20 days	11 days	9 days	11 days
7	POH	6 years ± 3 months or 15 lakh km	9 years ± 6 months or 24 lakh km	9 years ± 6 months or 24 lakh km	10 years ± 3 months or 12 lakh km	12 years ± 6 months or 24 lakh km
	Time Reqd.	24 days	20 days	20 days	28 days	20 days

Table 9A: Maintenance & Overhauling Schedule of Electric Locomotives

Sl. No.	Maintenance and Overhauling Schedules	Locomotive Class	
		ALCo	HHP
1	Trip or Weekly	15, 20, 30 & 40 days	Trip/ 30 days
2	Fortnightly	15, 20, 30 & 40 days	-

3	Monthly	60 days	-
4	Quarterly	120 days	90/ 180 days
5	Half Yearly	12 Months	-
6	Yearly	24 Months	1 year
7	2 yearly	-	2 year
8	3 Yearly	48 Months	3 year
9	6 yearly	-	6 year
10	POH	8 years	18 year

Table 9B: Maintenance & Overhauling Schedule of Diesel Locomotives

3.4.1 Degraded Mode Methods & Procedures

Although the locomotives are maintained and serviced as per the scheduled periodicity as detailed in the above mentioned table – 7 and 8 and certified as Zero defect by the competent locomotive engineer before turning out from their respective locomotive sheds yet in some events of failure of a component or sub system during the course of operation, locomotives are allowed to continue in service in a restricted manner instead of isolating from train operation. These conditions are tabulated in the table below:

Sl. No.	Failure Mode	Degraded Mode Methods & Procedures
A	3 Phase Locomotives WAP7 & WAG9	
1	One Bogie with 3 Traction Motors Isolated due to multiple causes of failure.	Only Half Traction and Braking power available, operation is continued if load permits.
2	One Line Contactor failed and Isolated	Operation is continued at reduced 75% Power
3	One Traction inverter failed and Isolated	Operation is continued at reduced 83.3% Power
4	Auxiliary Converter failed and Isolated	Ventilation level reduced, frequent checking of Auxiliaries
5	Harmonic Filter failed and Isolated	Speed reduces to 40 Kmph.
B	Conventional Locomotives	
1	MVSL not working (Blower motor for smoothening reactor)	Isolate defective Blower – Clear Block section with max current limited to 500amp.
2	MVRH not working (Blower motor for Radiator)	Clear Block section, following current rating.
3	MVMT not working (Blower motor for Traction Motor)	Corresponding Block isolated: Operation is continued if Load permits.
4	MVSI not working (Blower motor for Silicon Block)	Corresponding Block isolated: Operation is continued if Load permits.
C	Locomotive Equipments	
1	Horn/ Whistle becomes defective during operation	Speed restriction: 40 Kmph. Day time: Work up to destination Night time: Only Clear the Block Section
2	Head light goes out of order	Speed restriction: 20 Kmph during night or visibility not clear.
3	Driving Cab fails	Drive from rear cab at speed not exceeding 40 Kmph.
4	Speedometer defective	Train run with 10% less than Maximum Permissible Speed
D	Crew (Loco Pilot)	
1	Loco Pilot Incapacitated	Assistant Loco Pilot, if competent to clear the Block Section at speed not exceeding 25 Kmph.

Table 10: Degraded Modes, Methods & Procedures in Locomotives

The above mentioned methods provide resilience in the use of locomotives in degraded mode of operation instead of taking the locomotive out of service or occupying the block section for other operation.

3.5 Rolling Stock

Indian Railways uses mainly two different designs of passenger coaches, viz. Integral Coach Factory (ICF) and Linke Hofmann Busch (LHB), which are certified for their speed potential of 130 and 160 Km/h respectively. Similarly, 42 different varieties of freight carrying wagons of speed potential varying from 60 to 100 Km/h over a standard track layout are in use over IR. All rolling stocks are tested and certified for their speed potential by Commissioner of Railway Safety after speed trials and Oscillation tests report produced by the team of rolling stock Engineers from Research, Design, Standards Organisation of IR. For effective maintenance of the passenger coaches in good fettle and zero defect condition so as to run them at sanctioned speed potential, a system of Coaching Depots responsible for primary maintenance of nominated coaches is in place. However, this is not applicable for goods carrying wagons and the system of examination by Freight Examination Points (FEP) and issue of Brake Power Certificate (BPC) with certain validity is in place. These wagons are used during their BPC validity period by IR and offered to the nearest FEP for examination and issue of a fresh BPC. For overhauling schedules also, these wagons are offered to the nearest Carriage & Wagon workshop. The snapshot of schedule of maintenance of passenger carrying coaches is as below:

Sl. No.	Maintenance/ Examination Description	Periodicity as per Type of Trains and Coaches			
		Rajdhani/ Duranto	Shatabdi	Mail/ Express	Passenger
1	Preventive Maintenance Schedule at Pit line	At Primary End	At Primary End	At Primary end	At Primary end
2	Under gear examination and brake system maintenance at pit line.	At both the ends	At both the ends	At both the ends	Within 3500 Kms or 96 hours of original BPC at Primary End.
3	Enroute	\$	\$	\$	\$
4	Terminating Examination	At Terminating station.	At Terminating station.	At Terminating station.	At Terminating station.
5	Brake system check prior to start at platform at other end.	#	@	#, if Round Trip run > 3500 for ICF and 4000 Kms for LHB.	@

Table 11A: Maintenance Pattern of Coaching Trains (Mainline)

\$: After every 250 to 350 Kms of run or at the next nominated TXR point at stopping station.

#: Complete Air Brake Testing with issue of fresh BPC at both ends.

@: Only continuity check if stabled at platform, otherwise, brakes power check with endorsement on original BPC

Sl. No.	Maintenance/ Examination Description	Description of Conditions		
		BPC Validity	Re-examination	Man hours Required
1	Intensive	End to End	If Stabled for > 24 hrs	56
2	Closed Circuit Rakes	30 days or 6000 Kms of Run. (15 days from the date of issue of BPC if Kms not logged)	If Stabled for > 24 hrs	100
3	Premium	12 days	By Driver & Guard after every loading/ unloading	75

Table 11B: Maintenance Pattern of Freight Wagons

3.5.1 Degraded Mode Operation of Rolling Stocks: Mechanical Components

In spite of the above mentioned examination schedule and guidelines for maintenance, failure of some components of rolling stock or deterioration in parameters of wheels etc. may take place and detected during the rolling in examination. System of rolling – in- examination at every 250 – 300 Kms in place plays a very vital role in the detection of such failures or deterioration in the parameters, where rolling stock technician equipped with temperature guns and spot lights remain in position to thoroughly observe the under gears of rolling stock and take appropriate decision after noticing the defects. In case of serious defects, the rolling stock with defects is either detached from the train formation or allowed at restricted speed as follows:

Sl. No.	Nature of Defects Observed	Speed Restrictions imposed
1.	Broken Spring in LHB Coaches	80 kmph
2.	Broken Bolster Spring	60 kmph
3.	Axle Spring Primary directly attached to wheel set Broken	60-80 kmph
4.	Flat Tyres up to 50 mm LHB coach	80 kmph
5.	Flat Tyre more than 60 mm ICF Coach	80 kmph

3.5.2 Degraded Mode Operation of Rolling Stocks: Electrical Components

In addition, to the mechanical defects, limited failure of electrical equipment in the passenger coaches are taken care of by the alternative arrangements existing in the system, e.g. a failure of the power supply in coaches, inverters and 750V feeder line in LHB Coaches is taken care of by an emergency feed of electric supply from an adjoining coach, a second inverter and second feeder designed for taking care of full load respectively. These measures in place, provides resilience in the use of coaches in limited mechanical and electrical failure conditions.

4 SAFETY IN DEGRADED MODE OF OPERATION

Degraded modes of systems, methods and procedures are designed to provide the same level of safety as the normal mode of operation; however, due to involvement of human's in the process, the level of safety is dependent upon the error free implementation of methods, operation techniques and procedures by operators of



Figure 3: Flat Tyre

the systems like Loco Pilots, Station Masters, Guard of the train, Technicians (at TSS, SSP, SP, Locomotive sheds and Coaching depots) etc. Therefore, availability of fallback systems, documentation, knowledge and skill to correctly apply the procedures play a significant role in maintaining the better safety performance of IR as most of the accidents take place during a failure. A system of periodical medical test (PME), Psycho test and refresher training for operators and maintainers of various components and sub systems of IR infrastructure at prescribed schedule is in place and important to keep them fit and suitable for the task. The knowledge and skill acquired by these staff during their training and supervision by their immediate superiors

play a very crucial role in applying them during the failures and emergencies and maintaining the delivery of the transportation service of the same level of RAMS as designed for the normal mode of operation.

5 CONCLUSION

For the challenging transportation need of an ever growing Indian population and expanding economy, reliable rail transportation is the need of the hour. However, due to middle level speed potential of IR infrastructure and limited application of the most modern technology for condition monitoring of the infrastructure, which to the large extent depends upon the manual inspection, testing and measurement of track, signalling and operation, human factor plays a very crucial role in the utilisation of the full potential of the infrastructure, reliable and safe operation of trains and finally delivery of transportation services to the end user. Fallback systems, methods and procedures designed and implemented in the components and sub systems of IR have a critical role in delivering the rail transport services at the desired RAMS. Therefore, functioning of degraded mode of infrastructure, methods and procedures have a crucial role in maintaining train mobility in a safe and reliable manner during the

failure. Thus maintenance of Fallback systems in good fettle and use of methods and procedures in an error free manner is the key and this requires sustained inputs of training, knowledge, effective supervision and finally disciplined staff to achieve the objectives of the Indian Railways with resilience.

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