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Ground Penetrating Radar (GPR) Technology for Monitoring Health of Track Ballast Bed



M.K. Rajpal ED/GE RDSO, Lucknow



Vipin Kumar Jt. Director/GE RDSO, Lucknow



Satyam Singh SSE/GE RDSO, Lucknow



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Abstract: Railway track stability and safety significantly depend on the condition of the ballast bed, a crucial layer supporting the track structure. In India, where the railway network is among the most extensive and heavily utilized globally, maintaining the ballast bed presents considerable challenges due to environmental, geographical, and operational factors. Ground Penetrating Radar (GPR) has emerged as a reliable non-invasive tool to assess ballast condition effectively. This paper discusses the operational principles of GPR, its applications in ballast bed health monitoring, and its adaptation to Indian Railway conditions.

सारांश: रेलवे ट्रैक की स्थिरता और सुरक्षा काफी हद तक बैलास्ट बेड की स्थिति पर निर्मर करती है, जो ट्रैक संरचना को आधार प्रदान करने वाली एक महत्वपूर्ण परत है। भारत में, जहां रेलवे नेटवर्क विश्व स्तर पर सबसे व्यापक और भारी उपयोग में से एक है, बलास्ट बेड को बनाए रखना पर्यावरण, भौगोलिक और परिचालन कारकों के कारण काफी चुनौतियां पेश करता है। ग्राउंड पेनेट्रेटिंग रडार (जीपीआर) गिट्टी की स्थिति का प्रभावी ढंग से आकलन करने के लिए एक विश्वसनीय गैर—आक्रामक उपकरण के रूप में उभरा है। यह पेपर जीपीआर के परिचालन सिद्धांतों, बलास्ट बेड के स्वास्थ्य निगरानी में इसके अनुप्रयोगों और भारतीय रेलवे स्थितियों के लिए इसके अनुकूलन पर चर्चा करता है।

1. Introduction

Railways are a fundamental component of transportation infrastructure, playing a vital role in economic growth by providing an efficient and cost-effective mode of transportation. To ensure safety and timely freight and passenger transportation, the Railway system requires continuous maintenance, particularly of the track structure. The main components of the system are grouped into two main categories: superstructure and substructure. The superstructure consists of rail, fastening system, and sleepers. The substructure consists of ballast, blanket layer and subgrade. The substructure components, especially ballast, play an important role in maintaining track effectiveness. Hence, the quality of railway track depends on the characteristics and the general condition of all layers under the sleepers, particularly the ballast.

Proper Ballast bed ensures discharge of its various functions for satisfactory train running.

The main functions of ballast are to resist vertical, lateral, and longitudinal forces applied to sleepers to retain track in its required position, reduce pressure from the sleeper-bearing area to acceptable stress levels for the underlying material, provide resiliency and energy absorption for the track and provide immediate water drainage. Over time, ballast degrades due to mechanical stress, environmental exposure, and infiltration of fine particles, leading to ballast fouling.

Traditional ballast inspection methods, such as visual checks and manual probing, are laborintensive, time-consuming, and prone to subjectivity. To address these limitations, Ground Penetrating Radar (GPR) has emerged as a powerful tool for non-destructive ballast assessment, providing real-time data on ballast conditions without disrupting railway operations.

2. Ballast Fouling

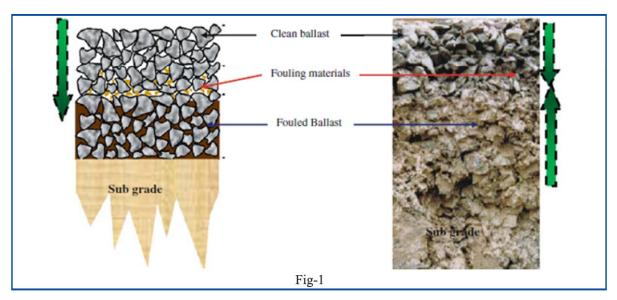
Ballast contamination or the filling of voids due

to ballast breakdown and infiltration of other materials from the ballast surface or infiltration from the base of the ballast layer is called ballast fouling.

With the passage of time ballast becomes foul or contaminated due to several factors i.e. (i) Ballast breakage, due to attrition on account of tamping as well as train running (ii) infiltration from ballast surface due to spillage of material from trains. (iii) infiltration of fine soil particles from underlying subgrade soil. (iv) Weathering of ballast (v) Environmental factors. Track stretches with bad formation suffers from high ballast degradation/ penetration and mud

pumping on sub grade material. These factors contribute to track geometry deterioration, requiring frequent track attention. Hence, periodic ballast screening and cleaning are necessary.

Figure 1 illustrates the typical fouling process and fouled ballast sections of the rail track. Fine ballast particles, resulting from ballast breakdown and material infiltration from railcars, migrate from the top to the bottom of the ballast layer. In this case elasticity and drainage capabilities of ballast bed reduces and all fines will be accumulated in the base of ballast layer as shown.



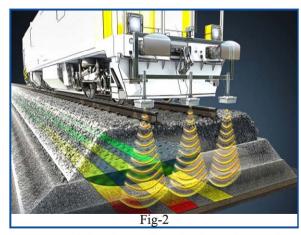
3. Indian Railways Ballast Specifications and Renewal Requirements

Indian Railways has specific standards for track ballast size & gradation and quality, laid down in Specifications for Track Ballast (IS/RDSO-GE/0001:2023). The ballast is typically made of hard, angular stones, with particle sizes between 20mm to 65mm. In India, heavy train traffic and diverse climatic conditions can accelerate ballast degradation, fouling, and contamination. With progressive fouling over a period of time, ballast renewal is required, which is currently decided based on manual measurement of clean ballast cushion-a subjective method that varies

depending on individual judgment. Accordingly, Ballast Cleaning Machines (BCMs) are deployed based on this assessment. Given these limitations, there is a need for an objective, scientific approach to establish criteria for deep screening. Implementing the use of GPR for deciding deep screening would help in decision-making for the judicious deployment of Ballast Cleaning Machines.

4. Ground Penetrating Radar (GPR) Technology

GPR is a non-invasive method that transmits electromagnetic waves into the ground. When these waves encounter changes in subsurface



materials, they reflect back to the receiver, enabling the detection of different materials based on their dielectric properties. In railway applications, GPR is mounted on inspection vehicles to scan tracks at speeds compatible with railway operations.

5. **GPR Components**

5.1 Antenna:

The antenna of a Ground Penetrating Radar

(GPR) system is one of its most critical components. Its primary functions are to transmit electromagnetic waves into the subsurface and receive the reflected signals that carry information about the subsurface materials and structures. In a Ground Penetrating Radar (GPR) survey, an air-coupled antenna is used to prevent damage from obstacles on track.

The antenna generates and emits electromagnetic waves into the ground. The frequency of the emitted wave determines the penetration depth and resolution. High-frequency waves provide high resolution but shallow penetration. Low-frequency waves penetrate deeper but have lower resolution. High frequency low wavelength (2GHz) waves address the concern of ballast fouling, clean ballast layer and water retention. Low frequency (400 – 700 MHz) high wavelength waves address the issues regarding ballast pockets, sign of formation failure, and development of water pockets in the railway formation.

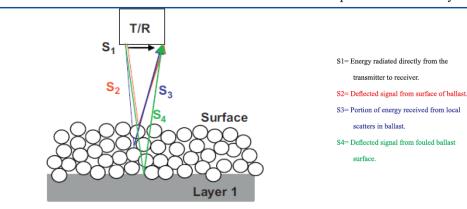


Fig-3- Path of EM Waves (T=transmitter R=receiver)

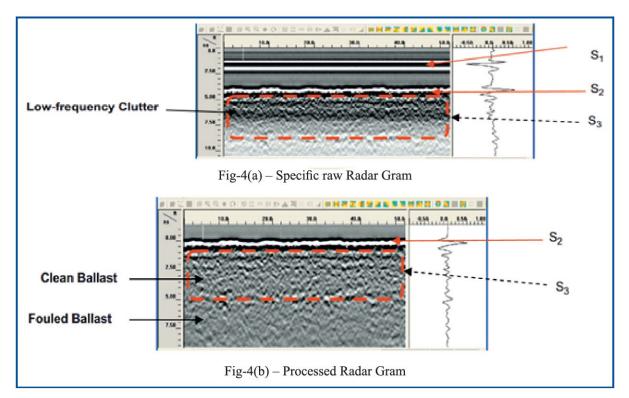
5.2 Control Unit and Data Acquisition Software:

It processes the reflected signals to create images or radar gram representing the subsurface structure. Fig. 4(a) and 4(b) shows the raw and processed 2 GHz GPR data. In Fig. 4(a), the low-frequency black band is clutter resulting from reflections produced by the rails. Raw GPR data collected must be processed to remove the clutter bands. Fig. 4(b) shows the processed result. The first pulse (S2) is the surface

reflection, and the subsequent small pulses (S3) are mainly from void space scattering. It is clear that appropriate data processing can effectively reduce the influence of rail echo and other clutter bands.

6. GPR and its Application in Assessment of Rail Track Ballast Fouling

GPR systems used for railway applications are impulse systems, which send short time-domain electromagnetic (EM) pulses and receive the



reflected pulses by an appropriate receiver. For track ballast, the reflected pulses could come from various sources: (a) the ballast surface (Signal S2 in Figure 3), in which the reflection amplitude is dependent on the dielectric constant of the clean ballast; (b) local scatters, that is, air voids within clean ballast (Signal S3 in Figure 3); and (c) the interface between clean ballast and fouled ballast if it is clear (Signal S4 in Figure 3). Signal S1 in Figure 3 represents the signal directly transmitted from the transmitter to the receiver.

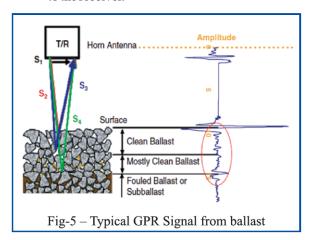


Figure 5 shows an example of a single-scan GPR signal collected from ballast by using a 2-GHz air-coupled antenna. The data within the circled area could be used to extract ballast fouling information. However, it should be noted that the information contained in the circled area is dependent on not only the air void distribution (size and shape) within the ballast (i.e., the fouling condition) but also the antenna frequency. When the air void size is close to the wavelength of the EM pulse, the air void can generate significant scattering to the GPR signal. Air void size of clean ballast is comparable to the wavelength of the 2-GHz antenna; therefore, significant scattering from air voids in clean ballast can be observed in the 2-GHz data.

To determine the thickness of clean ballast, the travel speed of the EM wave and the time within the ballast layer must be known. The travel speed of the EM wave can be determined from the dielectric constant of the ballast according to the following equation:

 $v=c/(\sqrt{\epsilon r})$

Where

v = wave propagation velocity c=speed of light in free space (3 x 10^8 m/s), and ϵr = dielectric constant of the medium. Therefore, to determine the thickness of the ballast, its dielectric constant must be known. However, in practice, the dielectric constants of ballast are usually unknown, which limits the accuracy of ballast thickness estimation.

Dielectric constants of common materials in Track bed component

Track bed component	Material type	Dielectric Constant εr
Ballast particles	Granite ballast	5–7
Ballast particles	Limestone ballast	4–8
Fouling material	Water	~80(frequency dependent)
Fouling material	Air	1
Fouling material	Sand	3–6
Fouling material	Soil	2–19
Fouling material	Clay	5–40
Fouling material	Ballast derived fines	4–8
Sub-ballast material	Sand	3–6
Sub-ballast material	Soil	2–19
Sub-ballast material	Bedrock	4–8

Once the dielectric constant is known, the thickness of the ballast can be calculated by using the following equation:

 $d=vt/2=ct/(2\sqrt{\epsilon r})$

Where d is the thickness of the ballast, and t is the two-way travel time of the GPR signal within the ballast. The two-way travel time is easy to determine when the interface between clean and fouled ballast is clear. However, in most field cases, the gradation of the ballast gradually changes, and there is no clear interface between fouled and clean ballast.

7. Calibration of GPR System

Calibrating a Ground Penetrating Radar (GPR) system for railway track inspection is essential to ensure the accuracy and reliability of the collected data. The calibration process involves adjusting the GPR system to account for environmental conditions, equipment variability, and the specific materials being analyzed.

After installation, GPR system shall be tested for flawless working by conducting repeatability test and reproducibility test over pre-decided stretch of railway track. As per European Standard EN 13848-2, 2020 Repeatability and Reproducibility are defined as follows:

7.1 Repeatability:

Degree of agreement between the values of successive measurements of the same parameter made under the same conditions, within a short period of time, where the individual measurements are carried out on the same section of track using the same measurement and interpretation methods, subject to the following controls:

- similar speed;
- same measuring direction;
- same vehicle orientation;
- similar environmental conditions

7.2 Reproducibility:

Degree of agreement between the values of successive measurements of the same parameter made under varying conditions, within a short period of time, where the individual measurements are carried out on the same section of track using the same measurement and interpretation methods, subject to one or more of the following:

- variation of speed;
- different measuring directions;
- different vehicle orientations;
- different environmental conditions

8. Challenges in Implementation of GPR on Indian Railways

8.1 High Initial Cost:

The acquisition and setup cost for GPR technology is high. However, conducting pilot projects to assess cost savings and efficiency improvements could justify the initial investment, potentially leading to broader adoption.

8.2 Climatic and Geographic Diversity:

India's extreme climatic conditions can impact GPR data accuracy. Equipment must be ruggedized, and data acquisition protocols may need modification to account for environmental variables, particularly in regions with high rainfall.

8.3 Data Interpretation Complexity:

Interpreting GPR data requires technical expertise and experience. Partnering with research institutions and utilizing AI-based software for data processing can help streamline this process, making it easier for field teams to extract actionable insights.

8.4 Integration with Existing Maintenance Practices:

On Indian Railways, traditional ballast assessment methods, including visual inspection, remain prevalent. A gradual integration of GPR data with existing maintenance systems, along with comparison studies, can facilitate a smooth transition to advanced monitoring.

8.5 Cost-Benefit Analysis:

While GPR technology has a significant initial cost, the benefits of improved track stability, reduced maintenance needs, and enhanced safety justify the investment. A cost-benefit analysis, comparing the long-term savings from condition-based maintenance and fewer track failures against the cost of GPR deployment, would provide Indian Railways with data to guide further implementation.

9. Conclusion

At present, deep screening criteria for ballast maintenance are subjective, relying on manual inspections and interpretation. GPR offers a scientific, objective approach to determine deep screening requirements, enabling data-driven planning of maintenance efforts, resource allocation, and machine deployment. By integrating GPR technology, Indian Railways can enhance track stability, optimize maintenance strategies, and improve overall railway safety. This advanced technology will also help in reducing maintenance costs and minimizing disruptions to train operations. Despite initial investment costs and data interpretation challenges, incorporating GPR into existing maintenance practices can significantly modernize railway infrastructure, making it more efficient and reliable for the future.

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Sustainable Transportation: Railways as a Greener Alternative to Roadways in India



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Abstract: This study undertakes a comprehensive analysis of carbon emissions in India's surface transportation sector, focusing on a comparative assessment between rail and road transport. Drawing upon historical data from 1951 and projections through 2030, it evaluates the critical role of Indian Railways in mitigating carbon emissions through electrification, operational efficiency improvements, and modal shifts. The findings reveal that railways emit significantly less CO₂ per tonne-kilometre and per passenger-kilometre compared to road transport. A key insight is the potential increase in the railway freight share to 45 percent by 2030, as envisaged under the National Rail Plan, which could result in a reduction of over 20 percent in total freight-related emissions despite increased railway activity. The study further explores the carbon-saving potential of multimodal logistics strategies, particularly Roll-On Roll-Off (RORO) services. Strengthening rail infrastructure and promoting sustainable practices emerge as pivotal strategies for lowering the sector's carbon footprint and meaningfully contributing to India's net-zero ambitions.

सारांश: यह अध्ययन भारत के सतही परिवहन क्षेत्र में कार्बन उत्सर्जन का व्यापक विश्लेषण प्रस्तुत करता है, जिसमें रेल और सड़क परिवहन के बीच तुलनात्मक मूल्यांकन पर ध्यान केंद्रित किया गया है। यह अध्ययन 1951 से ऐतिहासिक आंकड़ों और 2030 तक के अनुमानों के आधार पर भारतीय रेलवे की भूमिका का मूल्यांकन करता है कि वह विद्युतीकरण, परिचालन दक्षता में सुधार और परिवहन के साधनों में बदलाव (मॉडल शिफ्ट) के माध्यम से कार्बन उत्सर्जन को किस प्रकार कम कर सकती है। अध्ययन के निष्कर्ष बताते हैं कि टन-किलोमीटर और यात्री-किलोमीटर के हिसाब से रेलवे, सड़क परिवहन की तुलना में काफी कम CO, उत्सर्जित करता है। एक महत्वपूर्ण निष्कर्ष यह है कि राष्ट्रीय रेल योजना के तहत यदि रेलवे का माल परिवहन हिस्सा 2030 तक 45 प्रतिशत तक बढ़ता है, तो रेलवे गतिविधियों में वृद्धि के बावजूद कुल माल परिवहन से संबंधित उत्सर्जन में 20 प्रतिशत से अधिक की कमी आ सकती है। यह अध्ययन मल्टीमॉडल लॉजिस्टिक्स रणनीतियों, विशेष रूप से रोल-ऑन रोल-ऑफ (RORO) सेवाओं की कार्बन बचत क्षमता की भी पड़ताल करता है। रेल अवसंरचना को सुदृढ़ बनाना और सतत प्रथाओं को बढ़ावा देना, इस क्षेत्र के कार्बन पदिचह को घटाने और भारत की नेट-जीरो महत्वाकाक्षाओं में सार्थक योगदान देने के लिए महत्वपूर्ण रणनीतियाँ उमरती हैं।

1. Introduction

Transportation systems have evolved over centuries to fulfil the growing mobility needs of human societies, materializing primarily through road, rail, and air networks. While both road and rail infrastructures have expanded substantially worldwide, they have done so at different rates. Rail transportation offers substantial economies of scale for mass transit, significantly lowering emissions per transported unit. However, the proliferation of road networks and private vehicle ownership has increasingly marginalized the share of railways in surface transport.

Without active policy interventions and

behavioural shifts among businesses and individuals to prioritize rail travel, emission reduction goals will remain elusive. Recent research emphasizes that railways are particularly well-positioned to leverage electricity, renewable energy, and other low-carbon technologies especially through the operation of electrified systems more effectively than road transport. This study systematically explores the historical evolution of Indian Railways, evaluates its emission efficiency, and proposes strategies to enhance its role in sustainable transportation.

2. Historical Evolution and Key Advancements of Indian Railways

Indian Railways (IR), world's fourth largest

railway network (by route kilometer), commenced operations in 1853 with the launch of the first passenger train service between Mumbai and Thane, spanning 34 kilometres. Initially established under British colonial rule to facilitate trade and administration, the network grew rapidly over time. Following India's independence, Indian Railways underwent nationalization and consolidation, completing the unification of various private systems into a single entity by 1951.

Electrification efforts, first initiated in 1925 on the Mumbai suburban line, accelerated in the post-independence period. By 2024, over 97 percent of the Indian Railways network had been electrified, reflecting a significant shift towards sustainable operations by reducing reliance on fossil fuels. The launch of premium passenger services such as the Rajdhani Express in 1969 and the Shatabdi Express in 1988 marked critical milestones, enhancing intercity travel by improving speed, comfort, and connectivity.

The Konkan Railway project, completed in 1998, stands as a testament to Indian engineering prowess, successfully connecting the Western Ghats' challenging terrains. In the freight sector, Indian Railways transformed operations through the development of Dedicated Freight Corridors (DFCs), designed to support high-speed, high-capacity freight movement while decongesting passenger traffic. In 2019, the introduction of the indigenous Vande Bharat Express signalled India's entry into the realm of semi-high-speed rail technology, with projects such as the Mumbai-Ahmedabad bullet train expected to further revolutionize the sector.

Indian Railways has also embraced digital innovations, such as the IRCTC e-ticketing platform, real-time train tracking, and advanced signalling systems. Moreover, the organization continues to play a vital socio-economic role by enhancing rural connectivity and promoting tourism through luxury train services like the Palace on Wheels.

3. Indian Railways' Roadmap Towards Net Zero Emissions by 2030

Indian Railways has set an ambitious objective to achieve net zero carbon emissions by 2030. This vision is supported by strategies focused on enhancing energy security, improving operational efficiency, and integrating renewable energy sources across its networks. In terms of traction energy efficiency, Indian Railways has introduced energy-efficient rolling stock and deployed capacitor banks to maintain near - unity power factors. Smart rail energy grids are being developed and widespread electrification of tracks is underway. Shortdistance diesel services have been replaced by Electric Multiple Units (EMU), Mainline Electric Multiple Units (MEMU), and Vande Bharat rakes. Additionally, the adoption of Head-On-Generation (HOG) systems, which allow hotel load to be powered directly by locomotives, has further enhanced energy efficiency.

In the non-traction segment, Indian Railways has introduced energy-saving measures such as LED lighting, star-rated appliances, occupancy sensors, Building Management Systems (BMS), and Green Railway Station certifications. The sector has also prioritized the use of energy-efficient elevators and escalators with variable voltage and variable frequency technologies.

Indian Railways aims to meet an increasing proportion of its non-traction and traction energy demands through renewable sources, particularly distributed solar and wind projects. Supplementing these initiatives, the organization has targeted an increase in rail freight's share of land-based transport from 20 percent to 45 percent by 2030. It also plans to improve water use efficiency by 20 percent and enhance carbon sequestration through extensive tree plantation programs.

Collectively, these initiatives align Indian Railways with India's broader climate

commitments under the Paris Agreement and position it as a critical player in the national decarbonization strategy.

4. Comparison of Carbon Emission Savings: Rail versus Road (2022–23)

A comparative analysis of emission factors between rail and road transport in India clearly illustrates the environmental superiority of railways. For passenger transport, the emission factor for road-based passenger cars stands at 0.037667 kilograms of CO₂ per passengerkilometre, while that for railways is significantly lower at 0.009821 kilograms of CO2 per passenger-kilometre. This represents a 73.9 percent savings in emissions when choosing rail over private cars. Similarly, buses operating at 40 kilometres per hour and 60 kilometres per hour exhibit emission factors of 0.023094 and 0.029227 kilograms of CO₂ per passengerkilometre, respectively. Comparatively, the railways offer savings of 57.5 percent and 66.4 percent against these bus operations.

Freight transport analysis yields similar findings.

The road freight emission factors range from 0.021 kilograms to 0.035565 kilograms of CO₂ per tonne-kilometre, depending on vehicle speed and category. Rail freight, in contrast, emits only 0.008423 kilograms of CO₂ per tonne-kilometre. This results in emission savings ranging from 59.9 percent to 76.3 percent compared to road freight across various scenarios.

Overall, the analysis highlights the substantial carbon emission reduction potential of modal shifts towards rail-based transportation, both in passenger and freight segments. These findings are critical in guiding transportation policies towards more sustainable practices.

4.1 Analysis of CO₂ Emission Passenger Transport

The emission factors for Road transport, specifically buses and passenger cars, were compared to the emission factors for Rail passenger transport. Below is the detailed analysis:

Item (A)	Emission factor for Road Passenger Transport (Kg CO2/ Passenger-Km)	Emission Factor for Rail Passenger Transport (Kg CO2/Passenger-Km)	Emission Reduction factor (Kg CO2/Passenger - KM)	% Savings
A	В	$\boldsymbol{\mathcal{C}}$	D=(B-C)	E=(D/B)*100
Passenger Car Transport*	0.037667	0.009821	0.027845	73.9%
Passenger Bus Transport at 40 km/Hr**	0.023094	0.009821	0.013272	57.5%
Passenger Bus Transport at 60 km/Hr**	0.029227	0.009821	0.019406	66.4%

^{*}Calculated using CAFE Norms Stage I (2017-18 onwards)

The M3 category of vehicle is for motor vehicles that are used to transport passengers and have a maximum gross vehicle weight of more than 5 tons.

^{**}Calculated using fuel efficiency norms by GoI as per M3 motor vehicle category

4.2 Freight Transport CO₂ Emission Analysis

The emission factors for Road freight transport were compared to the emission factors for Rail freight transport to understand the potential CO2 savings:

Item (B)	Emission factor for Road Freight Transport (Kg CO2/ Ton-Km)	Emission factor for Indian Rail Freight Transport (Kg CO2/Ton - Km)	Emission Reduction factor (Kg CO2/Ton - KM)	% Savings
\boldsymbol{A}	$\boldsymbol{\mathit{B}}$	C	D=(B-C)	E=(D/B)*100
Freight Operation at 40 km/Hr#	0.021	0.0084231	0.0125768	59.9%
Freight Operation at 60 km/Hr#	0.028000	0.0084231	0.0195768	69.9%
Freight Operation at 40 km/Hr##	0.025908	0.0084231	0.0174848	67.5%
Freight Operation at 60 km/Hr##	0.035565	0.0084231	0.0271420	76.3%

[#] Calculated using fuel efficiency norms for different GWW categories (average)

Calculated using fuel efficiency norms by GoI as per N3 rigid vehicle category

N3 - It's a motor vehicle with at least four wheels, used to carry goods, and has a gross vehicle weight (GVW) of more than 12 tons.

4.3 CO₂ Savings Achieved Against Different Types of Road Transport Data

The analysis highlights the CO₂ savings achieved by Indian Railways for passenger and freight transport in comparison to various types of Road transport. The savings are based on emission factors derived from both Indiaspecific reports and global datasets:

Passenger Transport

- Against Car (Calculated using CAFE Norms Stage I (2017-18 onwards))
 - Road Emission Factor: 0.037667 Kg CO₂/Passenger-Km
 - o Rail Emission Factor: 0.009821 Kg CO₂/Passenger-Km
 - O CO, Savings: 73.9%
- Against Bus, Speed at 40km/hr (Calculated using fuel efficiency norms, M3 Vehicles Category) The M3 category of vehicle is for

motor vehicles that are used to transport passengers and have a maximum gross vehicle weight of more than 5 tons

- O Road Emission Factor: 0.023094 Kg CO₂/Passenger-Km
- O Rail Emission Factor: 0.009821 Kg CO₂/Passenger-Km
- O CO₂ Savings: 57.5%
- Against Bus, Speed at 60km/hr (Calculated using fuel efficiency norms, M3 Vehicles Category)

The M3 category of vehicle is for motor vehicles that are used to transport passengers and have a maximum gross vehicle weight of more than 5 tons

- O Road Emission Factor: 0.029227 Kg CO₂/Passenger-Km
- O Rail Emission Factor: 0.009821 Kg CO₂/Passenger-Km
- o CO, Savings: 66.4%

Freight Transport

N3 - It's a motor vehicle with at least four wheels, used to carry goods, and has a gross vehicle weight (GVW) of more than 12 tons

N3 Tractor & Trailer category - A vehicle used for the carriage of goods and having GVW exceeding 12 t

- Against Heavy-Duty Vehicles (Calculated using fuel efficiency norms, N3 Tractor & Trailer Vehicle Category, Speed at 40 km/hr)
 - O Road Emission Factor: 0.021 Kg CO₂/Ton-Km
 - O Rail Emission Factor: 0.008423173 Kg CO,/Ton-Km
 - O CO₂ Savings: 59.9%
- Against Heavy Goods Vehicles (Calculated using fuel efficiency norms, N3 Tractor & Trailer Vehicle Category, Speed at 60 km/hr)
 - O Road Emission Factor: 0.028000 Kg CO,/Ton-Km
 - O Rail Emission Factor: 0.008423173 Kg CO₂/Ton-Km
 - O CO, Savings: 69.9%
- Against Heavy Goods Vehicles (Calculated

using fuel efficiency norms, N3 Rigid Vehicle Category, Speed at 40 km/hr)

- O Road Emission Factor: 0.025908 Kg CO,/Ton-Km
- O Rail Emission Factor: 0.008423173 Kg CO,/Ton-Km
- O CO₂ Savings: 67.5%
- Against Heavy Goods Vehicles (Calculated using fuel efficiency norms, N3 Rigid Vehicle Category, Speed at 60 km/hr)
 - O Road Emission Factor: 0.035565 Kg CO/Ton-Km
 - O Rail Emission Factor: 0.008423173 Kg CO,/Ton-Km
 - O CO₂ Savings: 76.3%

The data underscores the potential of railways as a sustainable and eco-friendly transport mode, with considerable reductions in carbon emissions compared to Road transport alternatives.

[Source: CMAI Report on "Indicative CO₂ saving analysis for Indian Railways for the year 2022-23"]

5. Analysis of Changes in Transportation Sector Over Time

Year	Road Transport- Freight Movement (Numbers in Billion Tonnes Kilometres)	Road Transport- Freight Movement (% of Total Freight Movement)	Railways-Freight Movement (Numbers in Billion Tonnes Kilometres)	Railways-Freight Movement (% of Total Freight Movement)
1950-51	6	13.8	37.6	86.2
1960-61	14	16.2	72.3	83.8
1970-71	47.7	30.1	110.7	69.9
1980-81	90.9	38.1	147.7	61.9
1990-91	145.1	38.1	235.8	61.9
1999-00	467	60.5	305.2	39.5
2009-10	1015.1	62.8	600.5	37.2
2016-17	2226.5	78.22	620.1	21.78
2017-18	2484.8	78.19	692.9	21.81
2018-19	2697	78.50	738.5	21.50
2019-20	2927	80.53	707.6	19.47
	Extrapolating table upto yea per year annual grow	, .		

2020-21	3205.1	81.66	719.8	18.34
2021-22	3509.6	80.10	871.8	19.90
2022-23	3842.1	80.02	959.6	19.98
2023-24	4205.5	81.20	973.9	18.80
			Extrapolating table upto year 2029-30 by seeing ~10% per year annual growth rate from 2020-21	
2024-25	4602.8	81.12	1071.3	18.88
2025-26	5039.1	81.05	1178.4	18.95
2026-27	5517.2	80.98	1296.2	19.02
2027-28	6038.3	80.90	1425.8	19.10
2028-29	6605.7	80.81	1568.3	19.19
2029-30	7222.7	80.72	1725.1	19.28

Table1: Freight Traffic (Billion Tonnes KM) Source: MORTH & Indian Railways

India's inland transportation has seen a major shift in modal shares post-independence. Historically, railways dominated both freight and passenger movement. However, over the decades, road transport has expanded rapidly, primarily driven by improvements in highway infrastructure and the increasing preference for door-to-door services.

For freight movement, railways accounted for approximately 86.2 percent of the total freight in 1950-51. By 2019-20, this share had declined sharply to just 19.47 percent. Roadways, which constituted only 13.8 percent of freight movement in 1950-51, expanded their share to over 80 percent by 2019-20. Projections indicate that without major policy interventions, this trend will continue, with roadways maintaining dominance in the future.

In passenger transportation, the shift has been even more pronounced. Railways, which accounted for 74.3 percent of total passenger-kilometres in 1950-51, now contribute only 4 percent, while roadways dominate with a 96 percent share as of 2019-20. The aggressive expansion of national and state highways, coupled with the flexibility offered by road transport, has significantly eroded the railways' modal share.

This stark modal shift has important implications for national carbon emissions, given the higher emission intensities associated with road transport.

Indicative traffic of passengers and freight through Railways and Roadways are tabulated as below:

Year	Road Transport- Passenger Movement (Numbers in Billion Passenger Kilometres)	Road Transport- Passenger Movement (% of Total Passenger Movement)	Railways-Passenger Movement (Numbers in Billion Passenger Kilometres)	Railways- Passenger Movement (%of Total Passenger Movement)
1950-51	23	25.70	66.5	74.30
1960-61	80.9	51.01	77.7	48.99
1970-71	210	64.00	118.1	36.00
1980-81	541.8	72.20	208.6	27.80
1990-91	767.7	72.20	295.6	27.80

1999-00	1831.6	80.96	430.7	19.04
2009-10	5555.9	86.01	903.4	13.99
2016-17	11140	90.64	1149.8	9.36
2017-18	20237	94.50	1177.6	5.50
2018-19	22582	95.13	1157.1	4.87
2019-20	25199	96.00	1050.7	4.00
	Extrapolating table upto ye 11.5% per year annual grow			
2020-21	28100.00	99.18	231.12	0.82
2021-22	31342.70	98.15	590.21	1.85
2022-23	34947.10	97.33	959	2.67
2023-24	38946.20	97.34	1064.70	2.66
			Extrapolating table upto year 2.62% per year annual growth irregular previous	rate as per NRP due to
2024-25	43378.10	97.46	1092.60	2.46
2025-26	48285.70	97.58	1121.22	2.27
2026-27	53718.60	97.69	1150.60	2.10
2027-28	59732.10	97.80	1180.74	1.94
2028-29	66388.20	97.90	1211.68	1.79
2029-30	73756.00	98.00	1243.42	1.66

Table2: Passenger Traffic (Billion Passengers KM) Source: MORTH & Indian Railways

6. Electrification Milestones: Driving Down Emissions

The electrification of the Indian Railways network has been a major contributor to lowering emissions from the sector. Starting with just 388 route kilometres electrified in 1951, Indian Railways has progressively accelerated the electrification process. By 2024, approximately 64,982 route kilometres have been electrified, representing 97.65 percent of the entire network.

This shift to electric traction has significantly curtailed diesel consumption and associated emissions. Furthermore, it has enabled the integration of renewable energy sources into the operational energy mix, paving the way for greener transportation alternatives.

Decade wise electrification percentage is calculated with respect to current route km figure.

Year	Electrified Rkm	% Electrification
1951	388	0.58
1961	748	1.12
1971	3706	5.57
1981	5345	8.03
1991	9968	14.98
2001	14856	22.32
2011	19607	29.46
2021	45772	68.78
2022	51804	77.85
2023	58074	87.27
2024	64982	97.65

Table3: Railways Electrification trend Source: IR Year Book 2023-24 & RB(RE) Directorate

7. Analysis of Carbon Emissions in the Transportation Sector

The calculation of indicative carbon emissions based on standard emission factors reveals critical insights into the environmental impact of rail and road transport modes. In 1950-51, railways contributed approximately 0.97 million tonnes of CO_2 emissions, whereas roadways accounted for 0.86 million tonnes. By 2019-20, emissions from roadways had surged dramatically to approximately 836.71 million tonnes, compared to 16.28 million tonnes from railways.

Projections indicate that by 2029-30, emissions from roadways could reach 2,411.86 million tonnes, while those from railways are expected to increase modestly to 26.74 million tonnes. These figures underline the urgent need for policy interventions aimed at increasing railways' share of freight and passenger

transport to curtail national transportation emissions.

Further analysis suggests that if the National Rail Plan target of achieving a 45 percent railway share in freight transport by 2030 is realized, total freight-related emissions could reduce by approximately 21 percent compared to the current growth trajectory. Although railway emissions would increase slightly due to greater volumes, the overall environmental gain would be substantial.

We can calculate indicative carbon emission by both modes from Table 1 and Table 2 by multiplying through these emission factors.

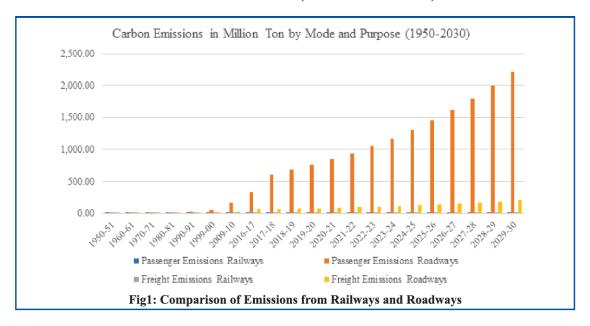
X 7	Passenger Emissions		Freight Emissions	
Year	Railways	Roadways	Railways	Roadways
1950-51	0.65	0.69	0.32	0.17
1960-61	0.76	2.43	0.61	0.39
1970-71	1.16	6.30	0.93	1.32
1980-81	2.05	16.25	1.24	2.51
1990-91	2.90	23.03	1.99	4.01
1999-00	4.23	54.94	2.57	12.90
2009-10	8.87	166.65	5.06	28.04
2016-17	11.29	334.16	5.22	61.49
2017-18	11.57	607.03	5.84	68.63
2018-19	11.36	677.37	6.22	74.49
2019-20	10.32	755.87	5.96	80.84
2020-21	2.27	842.89	6.06	88.52
2021-22	5.80	940.16	7.34	96.93
2022-23	9.42	1,048.27	8.08	106.11
2023-24	10.46	1,168.23	8.20	116.15
2024-25	10.73	1,301.17	9.02	127.12
2025-26	11.01	1,448.38	9.93	139.17
2026-27	11.30	1,611.34	10.92	152.37
2027-28	11.60	1,791.72	12.01	166.77
2028-29	11.90	1,991.38	13.21	182.44
2029-30	12.21	2,212.38	14.53	199.48

Table 4: Emissions (Million Tonnes of CO₂)

Year	Railways	Roadways	Total
	v		
1950-51	0.97	0.86	1.83
1960-61	1.37	2.81	4.19
1970-71	2.09	7.62	9.71
1980-81	3.29	18.76	22.06
1990-91	4.89	27.04	31.92
1999-00	6.80	67.84	74.64
2009-10	13.93	194.69	208.62
2016-17	16.52	395.65	412.16

17.40	675.65	693.06
17.58	751.86	769.44
16.28	836.71	852.99
8.33	931.41	939.74
13.14	1,037.08	1,050.22
17.50	1,154.38	1,171.89
18.66	1,284.38	1,303.04
19.75	1,428.29	1,448.04
20.94	1,587.55	1,608.49
22.22	1,763.72	1,785.94
23.61	1,958.49	1,982.10
25.11	2,173.82	2,198.93
26.74	2,411.86	2,438.60
	17.58 16.28 8.33 13.14 17.50 18.66 19.75 20.94 22.22 23.61 25.11	17.58 751.86 16.28 836.71 8.33 931.41 13.14 1,037.08 17.50 1,154.38 18.66 1,284.38 19.75 1,428.29 20.94 1,587.55 22.22 1,763.72 23.61 1,958.49 25.11 2,173.82

Table 5: Total Emissions (Million Tonnes of CO₂)



If railway freight transport grows to 45% of total freight movement by 2030 as per NRP 2020, it would significantly reduce overall emissions,

because Railways are much more emission-efficient compared to Roadways.

Year	Road Transport- Freight Movement (Numbers in Billion Tonnes Kilometres)	Road Transport- Freight Movement (% of Total Freight Movement)	Railways- Freight Movement (Numbers in Billion Tonnes Kilometres)	Railways- Freight Movement (% of Total Freight Movement)
2029-30(as per current growth)	7222.7	80.72	1725.1	19.28
2029-30(as per NRP 45% Railway freight share)	4921.29	55.0	4026.51	45.0

Year	Freight Emission(Million Tons of CO2)		
	Roadways	Railways	Total
2029-30(as per	199.48	14.53	214.01
current growth)			
2029-30(as per	135.92	33.92	169.84
NRP 45% Railway			
freight share)			

Key Insights:

- As per current growth rate in freight transportation projected Freight emission (Rail + Road) in 2029-30 will be approx. 214 Million tons of CO₂ but transitioning to 45% Railway freight share under NRP reduces total freight emissions by 44.17 million tons of CO₂, which is roughly a 21% reduction.
- Though Railway emissions increase, the overall emissions drop significantly due to a substantial reduction in high-emitting Road freight.

8. Case Study: Rail versus Road Transportation and Carbon Emissions

A detailed case study comparing the transportation of coal over a distance of 3000 kilometres by rail and road highlights the stark difference in carbon emissions. Using rail transport with BOXNHL wagons carrying 3762 tonnes results in a total emission of 95.3 tonnes of CO₂. In contrast, transporting the same quantity by heavy goods vehicles on the road results in emissions of 401.3 tonnes of CO₂, approximately four times higher.

When considering a multimodal strategy, wherein 80 percent of the distance is covered by rail and 20 percent by road (typical of Roll-On Roll-Off services), the total emissions stand at 156.4 tonnes of CO₂. Even in this mixed model, emissions are reduced by approximately 61 percent compared to a purely road-based transport approach.

This case study underscores the environmental benefits of adopting rail and multimodal transport systems for freight movement in India.

Case 1: Rail Transportation

- Mode: Rail Transportation using BOXNHL wagons
- Rake Size: 58 wagons
- Loading Size: 57 wagons
- Carrying Capacity per Wagon: 66 Tonnes
- Total Tonnage: 57 * 66 = 3762 Tonnes
- Distance: 3000 Km
- Tonnage-Km: 3762 * 3000 = 11286000 TKM
- Rail Emission Factor: 0.00844383 Kg-CO₂/TKM
- CO₂ Emission Calculation: CO₂ Emission = 11286000 TKM * 0.00844383 Kg-CO2/TKM CO2 Emission = 95297 Kg = 95.3 Tonnes

Case 2: Road Transportation

- Mode: Road Transportation using Heavy Vehicle Goods (N3 Rigid Vehicle Category at 60 KMPH)
- Total Tonnage: 3762 Tonnes
- Distance: 3000 Km
- Tonnage-Km: 11286000 TKM
- Road Emission Factor: 0.035565 Kg-CO₂/TKM
- CO₂ Emission Calculation: CO_2 Emission = $11286000 \text{ TKM} * 0.035565 \text{ Kg-CO}_2/\text{TKM CO}_2$ Emission = 401386.59 Kg = 401.3 Tonnes

Case 3: Multimodal Transportation (Rail + Road)

- Route Split: 80% Rail and 20% Road
- Rail Route: 2400 Km (80%)
- Road Route: 600 Km (20%)
- Total Tonnage: 3762 Tonnes
 - **Rail Transport Calculation:** Tonnage-KM = 3762 * 2400 = 9028800 TKM CO, Emission =
 - $9028800 \text{ TKM} * 0.00844383 \text{ Kg-CO}_2/\text{TKM} =$

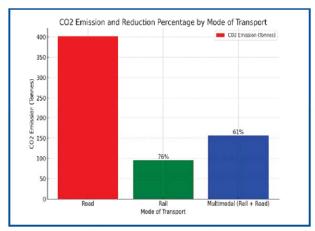
 $76237 \, \text{Kg} = 76.2 \, \text{Tonnes}$

Road Transport Calculation: Tonnage-KM = 3762 * 600 = 2257200 TKM CO₂ Emission = 2257200 TKM * 0.035565 Kg-CO₂/TKM = 80277.31 Kg=80.2 Tonnes

Total Emission in Multimodal Transportation

: CO₂ Emission = 76.2 Tonnes + 80.2 Tonnes = 156.4 Tonnes

Comparison of Carbon Emissions:



Mode of Transport	CO2 Emission (Tonnes)	Percentage Reduction
Rail	95.3	76% (Compared to Road)
Road	401.3	-
Multimodal (Rail + Road)	156.4	61% (Compared to Road)

The comparative analysis highlights that Rail transportation emits significantly less CO₂ compared to Road transportation. Multimodal transportation using RORO mode also demonstrates a substantial reduction in emissions compared to Road transport alone. Adopting Rail and multimodal transport systems can significantly contribute to reducing the carbon footprint in logistics operations and promote sustainable transportation practices.

9. Strategies to Promote Multimodal Freight and Passenger Transport

Promoting multimodal transport requires a comprehensive and integrated approach. For the

freight sector, expanding Roll-On Roll-Off services and developing multimodal logistics parks will be critical. Improving first- and last-mile connectivity between rail terminals and production or consumption centres is essential to ensure seamless intermodal transfers. The use of digital technologies for real-time freight tracking, centralized booking platforms, and improved freight scheduling will further enhance efficiency.

In passenger transport, the development of Integrated Multimodal Terminals that link rail stations with metro, bus, taxi, and air services will improve travel convenience. Implementing unified ticketing systems that allow passengers to use a single platform for various modes will facilitate a shift towards multimodal transport options. These initiatives must be supported by strong institutional coordination among ministries and agencies, incentives for private investment, and the standardization of infrastructure to ensure compatibility across modes.

Freight Transportation

Roll-on/Roll-off (RO-RO) Services

- Expand RO-RO services where trucks are loaded directly onto flatbed wagons.
- Useful in regions with poor Road infrastructure or for reducing Road congestion and pollution.
- Promote use on routes with difficult terrain or high freight demand (e.g., North East, hilly regions, border logistics).
- Coordinate with state governments and NHAI for last-mile integration and dedicated RO-RO terminals.

Development of Multimodal Logistics Parks (MMLPs)

- O Build large logistics hubs integrating Rail, Road, and potentially water/air cargo.
- Ensure multimodal linkages with industrial zones and consumption centers.

• First- and Last-Mile Connectivity

- Strengthen Road linkages from Railway freight terminals to warehouses and markets.
- Use automated loading/unloading infrastructure to reduce delays.

• Integration with Industrial Corridors

 Link rail networks with major industrial corridors (DMIC, AMRUT, SEZs) to streamline logistics supply chains.

• Digital Freight Ecosystem

 Real-time cargo tracking, centralized booking platforms, and freight scheduling tools for better coordination across modes.

• PPP and Private Freight Terminals

 Encourage private players to develop and operate terminals with multi-modal handling capabilities.

Use of DFCs

 Optimize freight trains on Dedicated Freight Corridors with multimodal feeder connections for efficiency and speed.

Passenger Transportation

• Integrated Multimodal Terminals (MMTs)

O Develop stations as transport hubs with metro, bus, taxi and airport connectivity.

• Seamless Ticketing & Scheduling

 Implement Unified Smart Cards or Mobile Apps that allow bookings across rail, metro, buses, and more.

• Improved Wayfinding & Amenities

 Upgrade station areas with clear signage, multimodal information boards, and better access to last-mile options (like autos, erickshaws).

• Urban Planning Integration

 oAlign station redevelopment with Smart Cities and AMRUT for smooth urban mobility.

Mobility-as-a-Service (MaaS)

 oEncourage digital ecosystems offering endto-end journey planning and fare payment across modes.

Enablers and Policy Measures

- Institutional Coordination between Railways, highways, ports, and aviation ministries.
- Policy Support for multimodal transport including taxation parity, customs integration, and incentives.
- Capacity Building for Railway and logistics staff in multimodal operations.
- Infrastructure Standardization to ensure smooth modal transitions.

10. Way Forward for Carbon Emission Reduction in Indian Railways

- To drive meaningful reductions in carbon emissions, Indian Railways must pursue an integrated multimodal transport strategy. Railways should be positioned as the backbone of national transportation infrastructure, integrated seamlessly with road, waterway, and air transport systems.
- Specific measures to reduce railway emissions must include transitioning non-traction energy loads to green sources such as solar and wind energy. Indian Railways must aggressively pursue its 10-gigawatt renewable energy installation target by 2030. Attention should also be given to reducing fugitive emissions by adopting sustainable cooling technologies and phasing out harmful refrigerants.
- Furthermore, diesel consumption must be curtailed through the electrification of all remaining non-electrified routes and by promoting biofuels or hydrogen-based propulsion where electrification is not viable. Large-scale afforestation programs along railway tracks and in railway-owned lands can serve as significant carbon sinks. Efficient water management, including recycling and rainwater

harvesting, should be standard practices across railway installations.

 By adopting these measures, Indian Railways can not only contribute to India's climate goals but also become a global leader in sustainable rail transport.

11. Conclusion

This study demonstrates that Indian Railways offers a significantly more sustainable alternative to road transport for both freight and passenger movements. Through focused efforts on electrification, operational efficiency, renewable energy integration, and multimodal development, the Indian Railways can substantially reduce its carbon footprint. Achieving a 45 percent modal share in freight transport by 2030, as envisaged under the National Rail Plan, will be pivotal in mitigating transportation sector emissions. By strengthening infrastructure, modernizing operations, and encouraging shifts in user behaviour, Indian Railways can play a transformative role in shaping a low-carbon, resilient transport future for India.

12. Acknowledgements

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Public Procurement – Opportunities and Challenges



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Abstract: Public procurement is the procurement of goods, services and works done by government agencies utilizing public funds, like various ministries, departments, municipal and other local bodies, statutory corporations and public undertakings both at the Centre and at the State level. Globally, public procurement accounts for a substantial part of the global economy and in India, it constitutes about 30% of the GDP.

As public procurement utilizes a substantial portion of taxpayers' money, governments are expected to follow strict procedures to ensure that the process is fair, efficient, transparent and minimizes wastage of public resources. The increasing volume of public procurement opportunities in India, coupled with the scale and magnitude of government projects, holds tremendous economic potential for both local and overseas companies. The recent upward trend in procurement opportunity in India can be attributed to a variety of measures and initiatives.

This paper discusses in greater details about legal and regulatory public procurement framework, encouragement to Make in India initiatives of the government, national laws relevant to public procurement, opportunities, challenges and concerns and also the role of General Financial Rule promulgated by Ministry of Inance.

सारांश: सार्वजिनक खरीद, विभिन्न मंत्रालयों, विभागों, नगरपालिका और अन्य स्थानीय निकायों, सांविधिक निगमों और केंद्र तथा राज्य स्तर पर सार्वजिनक उपक्रमों जैसी सरकारी एजेंसियों द्वारा सार्वजिनक धन का उपयोग करके की जाने वाली वस्तुओं, सेवाओं और कार्यों की खरीद है। वैश्विक स्तर पर, सार्वजिनक खरीद वैश्विक अर्थव्यवस्था का एक बड़ा हिस्सा है और भारत में, यह सकल घरेलू उत्पाद का लगभग 30% है। चूंकि सार्वजिनक खरीद में करदाताओं के पैसे का एक बड़ा हिस्सा उपयोग किया जाता है, इसिलए सरकारों से यह सुनिश्चित करने के लिए सख्त प्रक्रियाओं का पालन करने की अपेक्षा की जाती है कि यह प्रक्रिया निष्पक्ष, कुशल, पारदर्शी हो और सार्वजिनक संसाधनों की बर्बादी को कम से कम करे। भारत में सार्वजिनक खरीद के अवसरों की बढ़ती मात्रा, सरकारी परियोजनाओं के पैमाने और परिमाण के साथ मिलकर, स्थानीय और विदेशी दोनों कंपिनयों के लिए जबरदस्त आर्थिक क्षमता रखती है। भारत में खरीद के अवसरों में हाल ही में हुई वृद्धि का श्रेय विभिन्न उपायों और पहलों को दिया जा सकता है। इस पत्र में कानूनी और विनियामक सार्वजिनक खरीद ढांचे, सरकार की मेक इन इंडिया पहलों को प्रोत्साहन, सार्वजिनक खरीद से संबंधित राष्ट्रीय कानूनों, अवसरों, चुनौतियों, विंताओं और वित्त मंत्रालय द्वारा प्रख्यापित सामान्य वित्तीय नियम की भूमिका के बारे में अधिक विस्तार से चर्चा की गई है।

1.0 Introduction

Government procurement or public procurement is the procurement of goods, services and works on behalf of a public authority, such as a government agency. Globally, government procurement accounts for a substantial part of the global economy. In India, government procurement constitutes about 30% of the GDP. Governments, just like private companies, have to buy goods and services for their operational needs. Procurement of goods and services is carried out by various ministries, departments, municipal and other local bodies, statutory corporations and public undertakings both at the Centre and at the State level. Promotion of efficiency.

As public procurement utilizes a substantial portion of taxpayers' money, governments are expected to follow strict procedures to ensure that the process is fair, efficient, transparent and minimizes wastage of public resources. To prevent fraud, waste, corruption, or local protectionism, the laws of most countries regulate government procurement to some extent. Laws usually require the procuring authority to issue public tenders if the value of the procurement exceeds a certain threshold. Government procurement is also the subject of the Agreement on Government Procurement (GPA), a plurilateral international treaty under the auspices of the World Trade Organization.

The increasing volume of public procurement opportunities in India, coupled with the scale and magnitude of government projects, holds tremendous economic potential for both local and overseas companies. The recent upward trend in procurement opportunity in India can be attributed to a variety of measures and initiatives.

2.0 Legal and regulatory public procurement framework

The legal and regulatory public procurement framework in India broadly comprises the following elements:

i. Constitutional provisions: The Constitution of India authorises the Central and State Governments to contract for goods and services in the name of the President of India or the Governor of the State (respectively), and directs autonomy in public spending. However, it does not stipulate any procurement policies or procedures.

ii. Legislative provisions:

- 1) There is no comprehensive central legislation exclusively governing public procurement. Nonetheless, various procurement rules and policies (see below) are guided by central legislations such as the Contract Act 1872, Sale of Goods Act 1930, Prevention of Corruption Act 1988, Arbitration and Conciliation Act 1996, etc.
- 2) In addition, certain states, like Tamil Nadu, Karnataka, Andhra Pradesh, Assam and Rajasthan have enacted state-specific legislation such as the Tamil Nadu Transparency in Tenders Act, 1998, Karnataka Transparency in Public Procurement Act, 1999, the Rajasthan Transparency in Public Procurement Act, 2012, etc., that govern procedure for procurement in these states.

iii. Administrative guidelines:

a) Comprehensive administrative rules and directives on financial management and

- procedures for government procurement are contained in the General Financial Rules (GFR) initially implemented in 1947 and last modified in 2017. All government purchases must strictly adhere to the principles outlined in the GFR, which include specific rules on procurement of goods and services and contract management.
- b) In addition, the Manual for Procurement of Goods, 2017 (MPG) contains guidelines for the purchase of goods, and the Delegation of Financial Powers Rules, 1978 (DFPR) delegate the government's financial powers to various ministries and subordinate authorities.
- c) In 2017, the government issued the Public Procurement (Preference to Make in India) Order 2017 which grants purchase preference to local suppliers based on certain conditions so as to promote manufacturing and production of goods and services in India.
- iv. Overseers: The framework is bolstered by authorities including: (a) the Central Vigilance Commission (CVC) tasked with increasing transparency and objectivity in public procurement; (b) the Competition Commission of India (CCI) which checks anti-competitive elements; and (c) the Central Bureau of Investigation (CBI) engaged for investigation and prosecution of the criminal activities in the procurement process such as probity issues.

In summary, a public procurement process must adhere to: (i) GFR and MPG; (ii) sector-specific procurement rules contained in manuals published by the relevant ministry; and (iii) state-specific legislation on transparency in procurement. As between the procurer and the supplier, these rules above flow down via a tender award and a contract.

3.0 Public Procurement (Preference to Make in India)

Government has issued Public Procurement (Preference to Make in India) to encourage 'Make in India' and to promote manufacturing and production of goods, services and works in India with a view to enhancing income and employment. This Order is issued pursuant to Rule 153 (iii) of the General Financial Rules 2017. The salient features of the aforesaid Order are as under:

- The Order is applicable for procurement by Ministry / Department / attached / subordinate office of, or autonomous body controlled by, the Government of India and includes Government companies as defined in the Companies Act.
- In procurement of all goods, services or works in respect of which the Nodal Ministry/ Department has communicated that there is sufficient local capacity and local competition, only 'Class-I local supplier', as defined under the Order, shall be eligible to bid irrespective of purchase value.
- The margin of purchase preference shall be 20%.
 'margin of purchase preference' means the maximum extent to which the price quoted by a local supplier may be above the L1 for the purpose of purchase preference.
- Classes of Local Suppliers based on local content as per the revised PPP-MII Order dated 04.06.2020 issued by the Department for Promotion of Industry and Internal Trade (DPIIT) are as under:
- Class-I Local supplier a supplier or service provider, whose goods, services or works offered for procurement, has local content equal to or more than 50%.
- Class-II Local supplier a supplier or service provider, whose goods, services or works offered for procurement, has local content more than 20% but less than 50%.
- **Non-Local supplier** a supplier or service provider, whose goods, services or works offered for procurement, has local content less than or equal to 20%.
- Only 'Class-I local supplier' and 'Class-II local supplier' shall be eligible to bid in

procurement of all goods, services or works, and with estimated value of purchases less than Rs. 200 crore.

Government E-Market Place (GeM) Portal and NICSI, the two major procurement agencies of Government of India, are expected to ensure compliance of the Electronic Products Notification in their procurement. In case of a complaint Standardisation Testing and Quality Certification (STQC) will be the agency to look into the domestic value addition.

4.0 Basic Underlying Principles

India's regulatory and institutional framework seeks to ensure responsibility, accountability and efficiency in the public procurement regime. The underlying principle is to procure materials/services of specified quality at the most competitive prices in a transparent and non-arbitrary manner. Typically, various processes in Public Procurement involved include (1) Need, (2) Procurement Planning, (3) Requirement Specification, (4) Tender Preparation, (5) Tender evaluation, (6) Contract Award and (7) Contract Performance.

This is evident in the GFR which declares that all authorities delegated with the financial powers of procuring goods in public interest will be responsible and accountable to ensure efficiency, economy and transparency, fair and equitable treatment of suppliers, and the promotion of competition in public procurement. To this end, specific measures have been set out under the GFR including adherence to a code of integrity to address probity issues, etc.

Further, the Supreme Court of India has recognised that while the government must have freedom of contract:

- all contracts by the State should only be granted by public auction/tenders to ensure complete transparency and provide all eligible persons with the opportunity to participate in the auction;
- ii. all official acts must be actuated by public

interest, and should inspire public confidence;

- iii. generally, the State should not grant contracts by private negotiation (subject to certain exceptions based on the nature of the trade, emergency circumstances, single source supply, etc.); and
- iv. appearance of public justice is as important as doing justice (i.e. government actions should not only be fair but should also be seen to be fair, and nothing should be done which gives an impression of bias, favoritism or nepotism).

The regulatory framework covers all contracts offered by the government at the central, state or local level. Examples of types of contracts covered include PPP contracts, concession agreements, operation and maintenance contracts, engineering procurement and construction contracts, supply of equipment, supply of services, transfer of technology, etc.

4.1 Sectors Specific Special Rules in Procurement

There is no comprehensive central legislation exclusively governing public procurement in India. Instead, the public procurement regime comprises a framework of overlapping administrative rules and guidelines, sector-specific manuals and state-specific legislation.

- i. Defence: Governed by the Defence Procurement Procedure, 2016 (DPP) and the Defence Procurement Manual 2009 (as amended from time to time) which envisage various modes of procurement including indigenous, capital, local purchase, etc.
- ii. Railways: Governed by a number of specific laws and uses the Indian Railway e-Procurement Systems (IREPS) for procurement.
- iii. Energy: New Exploration Licensing Policy (NELP) under the Petroleum and Natural Gas Regulatory Act, 2006, provides for the evaluation of bids according to a quantitative bid evaluation criterion.
- iv. Electronics: The Preference for Domestically Manufactured Electronic Products Policy

- (2013) applies to all ministries/departments (except the Ministry of Defence) for electronic product procurement for government purposes.
- v. Electricity: Electricity Act, 2003 provides for the determination of tariffs through bidding processes by distribution licensees for the procurement of power.
- vi. **Telecoms:** Guided by the National Telecom Policy (currently in the process of being reworked to transition from physical to digital infrastructure. See question 8.1 below).
- vii. Renewables: The Ministry of New & Renewable Energy has released a National Policy on Biofuels and a Strategic Plan for New and Renewable Energy Sector. In 2017, the government issued guidelines for wind power procurement to enable the distribution licensees to procure wind power at competitive rates in a cost-effective manner.
- viii. Micro, small and medium-sized enterprises (MSMEs): Under the Public Procurement Policy for Micro and Small Enterprises Order 2012, a minimum of 20% of annual value of goods/services of the Central Government and public sector undertakings (PSUs) must be procured from micro and small enterprises (with further reservation of 4% in favour of MSMEs owned by 'backward classes').
- ix. **Pharmaceuticals:** Pharmaceutical Purchase Policy 2013 reserves the procurement of certain medicines from Central Public Sector Enterprises.

5.0 National Laws - Relevant to Public Procurement

Transparency, competition and curbing of probity issues are further ensured through:

- Competition Act, 2002: Penalises anticompetitive activities such as bid rigging, collusive bidding, cartelisation, and abuse of dominance.
- ii. Right to Information Act, 2005: Promotes transparency in government dealings by

entitling Indian citizens to expeditiously procure information from the government through a "right to information" application.

iii. Integrity pact under the GFR and CVC guidelines: Addresses probity in procurement activities including through the appointment of an external monitor to mitigate corruption and ethical risks.

iv. Prevention of Corruption Act, 1988 and Prevention of Money Laundering Act, 2002:

Penalise bribery and money-laundering and provide for confiscation of property derived from money-laundering and other illicit activities.

6.0 Opportunities

One of such major initiative of Government of India (GOI) is that, foreign investors are today being granted greater access to the breadth of India's market than ever before. GOI has further liberalized investment and increased foreign direct investment inflow into India, easing investment caps and opening up previously restricted sectors to overseas investors. Another such an initiative towards modernizing existing infrastructure and equipment has also resulted in a number of procurement opportunities. Other new initiatives such as "Digital India" and "Make in India" are geared towards improved physical and social infrastructure, connectivity and local design and manufacturing capability. Nonetheless, working with the government can be a mixed bag of opportunities and challenges, and business exposure to the public sector is not without legal and compliance risks.

7.0 Challenges and Concerns

The principle underlying India's public procurement regime is the acquisition of materials and services of specified quality at the most competitive prices, in a transparent and non-arbitrary manner. Nonetheless, the absence of a central procurement regulation enabling procuring authorities with scope to tweak guidelines and contract format, leads to confusion on one hand and rigidity on the other. In fact, different agencies may even prescribe varying qualification criteria, financial terms, selection procedures etc. for similar public sector work.

Suppliers supplying goods and services to the Indian government must carefully navigate the convoluted procurement framework. Falling foul, inadvertently or otherwise, of any procurement conditions under the tender documents or the aforementioned rules and guidelines could result in the tender award being challenged / disqualified and the contract cancellation, and the supplier being blacklisted for up to 3 years.

In addition, supplying to the government may involve some unique risks and practical concerns, such as (1) Slow and complex tender process (2) Delayed decision - making, (3) Limited scope of negotiations (4) Legality in use of agents etc.

8.0 Conclusions

In the absence of any specific law, public procurement and other related financial matters are governed by GFR 2017 promulgated by the Ministry of Finance. These rules are applicable to all central ministries and their attached and subordinate bodies. These are also deemed to be applicable to the autonomous bodies which do not have their own government-approved financial rules.



Rashomon Effect and its Relevance in Material Science



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Abstract: The "Rashomon effect," originating from Akira Kurosawa's film Rashomon, describes how multiple, seemingly reliable observers can perceive and interpret the same event in drastically different and even contradictory ways, highlighting the subjective nature of truth and observation. While not directly a metallurgical concept, it has implications for understanding how different perspectives and biases can influence scientific observations and interpretations within the field.

सारांश: अकीरा कुरोसावा की फिल्म राशोमोन से उत्पन्न "राशोमोन प्रभाव" बताता है कि कैसे कई, विश्वसनीय पर्यवेक्षक एक ही घटना को बहुत अलग और यहां तक कि विरोधाभासी तरीकों से देख और व्याख्या कर सकते हैं, जो सत्य और अवलोकन की व्यक्तिपरक प्रकृति को उजागर करता है। हालांकि यह सीधे तौर पर एक धातु विज्ञान अवधारणा नहीं है, लेकिन यह समझने के लिए निहितार्थ है कि विभिन्न दृष्टिकोण और पूर्वाग्रह सोच की वजह से वैज्ञानिक अवलोकन और व्याख्याओं को कैसे प्रभावित कर सकते हैं।

1. Origin:

The term comes from Kurosawa's film Rashomon, which explores a crime through the conflicting testimonies of various characters, none of whom can agree on what actually happened.

2. Core Idea:

The Rashomon effect emphasizes that our perception of reality is always filtered through our individual biases, experiences, and perspectives.

3. Implications:

This can lead to:

- Conflicting Interpretations: Different researchers or metallurgists might interpret the same experimental data or material behaviour in vastly different ways.
- **Difficulty in Establishing Truth:** It becomes challenging to establish a definitive "truth" when multiple perspectives are at play.
- Importance of Critical Thinking: The Rashomon effect underscores the need for critical thinking and awareness of potential biases when analysing data and drawing conclusions.

4. Relevance to Metallurgy:

In the context of metallurgical analysis, the "Rashomon effect" refers to the situation where different analytical methods or interpretations of the same data lead to conflicting or contradictory conclusions, highlighting the subjectivity and potential biases inherent in the analysis process.

In metallurgy, this effect can manifest when:

- **Different Analytical Techniques:** (e.g., optical microscopy, electron microscopy, X-ray diffraction) yield seemingly contradictory results when characterizing the same material.
- Different Researchers or labs: interpret the same data (e.g., microstructure images, chemical analysis results) differently, leading to contrasting conclusions about the material's properties or behaviour.
- The choice of analytical parameters: (e.g., magnification, probe size, analysis time) can significantly influence the results, leading to different interpretations of the same data.

. (a) Consequences:

The Rashomon effect in Metallurgy can lead to:

Confusion and wasted time in materials

- characterization and property prediction.
- Misinterpretation of material behaviour and failure mechanisms, potentially leading to poor design choices or manufacturing processes.
- Difficulty in establishing a reliable and consistent understanding of complex metallurgical phenomena.

4. (b) Mitigation:

To mitigate the Rashomon effect, it's crucial to:

- Standardize analytical procedures and protocols across different labs and researchers.
- Use multiple analytical techniques: to crossvalidate results and gain a more comprehensive understanding of the material.
- Carefully document the analytical parameters and procedures used in each study to ensure reproducibility and comparability of results.
- Be aware of the limitations and potential biases associated with each analytical technique.
- Promote open communication and collaboration among researchers to facilitate a more holistic
 understanding of the material.

4 (c) Areas where effects generally noticed:

- In metallurgical failure analysis, multiple pieces of evidence (e.g., fracture surface characteristics, material properties, service conditions) might point to different or even opposing causes of failure.
- A fracture surface might show signs of both fatigue and brittle failure, requiring the analyst to determine the dominant failure mechanism.
- Material properties might deviate from expected values, potentially indicating improper manufacturing or environmental degradation, but the analyst must determine which is more likely.
- Service conditions might suggest a high stress level, but the material's microstructure might show signs of excessive creep, requiring the analyst to consider both factors.

5. Importance of Systematic Approach:

A systematic and thorough failure analysis process is crucial to mitigate the Rashomon effect, including:

- Thorough examination of the failed component.
- Collection of relevant data, including material properties, service conditions, and manufacturing history.
- Use of appropriate analytical techniques, such as metallography, microscopy, and chemical analysis.
- Careful consideration of all possible failure mechanisms.
- Reconciliation of conflicting evidence to arrive at a plausible explanation.

6. Important Tools and Techniques to overcome Rashoman effect:

- **Fractography:** Examination of fracture surfaces to identify the origin, propagation path, and mode of fracture.
- Metallography: Examination of the microstructure of the material to identify defects, inclusions, or other features that might contribute to failure.
- Scanning Electron Microscopy (SEM): A powerful tool for examining fracture surfaces and microstructures at high magnification.
- Energy-Dispersive X-ray Spectroscopy (EDS): Used to analyze the chemical composition of the material and identify any contaminants or corrosion products.

7. Conclusion:

In essence, the Rashomon effect serves as a reminder that:

- No single perspective is always the "truth."
- It's crucial to consider multiple viewpoints and potential biases.
- Critical thinking and awareness of potential limitations are essential in scientific research.



In-House Development of Computer Based Psychometric Test (CBT) Portal for In-service Safety Personnel of Indian Railways



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Abstract: The Indian Railways relies on psychometric evaluations to ensure that its in-service safety personnel such as loco pilots, motormen, station master etc maintain the cognitive acuity, psychomotor coordination, and psychological resilience required for safe train operations. Traditionally administered through pen-and-paper tests, the existing system is labour intensive, time consuming, and prone to human error. This article describes the design and development of an online Computer Based Psychometric Test (CBT) portal, named the "Computerized Aptitude Test System (CATS)", for conducting psychometric tests of in-service loco pilots. The system leverages open-source technologies with an architecture based on the Model-View-Template (MVT) framework using Django (Python), PostgreSQL, and HTML, CSS, jQuery & Bootstrap all served via Nginx. The CBT portal provides enhanced security via AES-256 encryption for test batteries, role-based access controls, randomized test generation, and two-step authentication, thereby improving security, efficiency, accuracy, and environmental sustainability. This article discusses the system's requirements, technical design, implementation challenges, and the benefits realized by transitioning from a manual to a computerized testing system.

सारांश: भारतीय रेलवे अपने सेवारत संरक्षा कर्मी जैसे कि लोको पायलट, मोटरमैन, स्टेशन मास्टर आदि की मानसिक तीक्ष्णता, मनःप्रेरक समन्वय और मानसिक लवीलापन सुनिश्चित करने के लिए साइकोमेट्रिक परीक्षणों पर निर्भर करती है, जो सुरक्षित ट्रेन संचालन के लिए आवश्यक हैं। परंपरागत रूप से कागज—कलम आधारित परीक्षाओं के जिए आयोजित, मौजूदा प्रणाली श्रमसाध्य, समय लेने वाली और मानवीय त्रुटियों के जोखिम से भरी हुई है। इस लेख में एक ऑनलाइन कंप्यूटर आधारित साइकोमेट्रिक परीक्षा (CBT) पोर्टल, जिसे "कंप्यूटरीकृत एप्टीट्यूड टेस्ट सिस्टम (CATS)" कहा गया है, के डिजाइन और विकास का विवरण प्रस्तुत किया गया है, जो सेवारत लोको पायलटों के मनोमितिक परीक्षणों के संचालन के लिए है। यह प्रणाली Django (Python) पर आधारित Model-View-Template (MVT) फ्रेमवर्क, PostgreSQL, HTML, CSS, jQuery और Bootstrap जैसी ओपन—सोर्स तकनीकों का उपयोग करती है और Nginx के माध्यम से प्रस्तुत की जाती है। CBT पोर्टल, AES-256 एन्क्रिप्शन द्वारा टेस्ट बैटरियों की सुरक्षा, भूमिका—आधारित एक्सेस कंट्रोल, यादृच्छिक परीक्षण निर्माण और दो—चरणीय प्रमाणीकरण जैसी सुविधाओं के साथ सुरक्षा, कार्यकुशलता, सटीकता और पर्यावरणीय स्थिरता में सुधार करता है। यह लेख प्रणाली की आवश्यकताओं, तकनीकी डिजाइन, कार्यान्वयन चुनौतियों और मैनुअल से कंप्यूटरीकृत परीक्षण प्रणाली में परिवर्तन से मिलने वाले लामों पर चर्चा करता है।

1. Introduction

Indian Railways has long recognized the importance of maintaining high safety standards in train operations. Psychometric testing plays a pivotal role in assessing both the cognitive and psychomotor skills required for safety-critical roles such as Assistant Loco Pilots, Motormen, Assistant Station Masters etc. These tests evaluate abilities including reaction time, attention, memory, depth perception, and the capacity to follow multi-step instructions. Furthermore, they assess personality traits, such as stress tolerance and decision-making under pressure, which are essential for effective crisis management.

Currently, these evaluations have been administered using pen-and-paper methods. However, with increasing operational complexity, an ageing workforce, and the growing demand for rapid, unbiased assessments, the need for a computer-based approach became apparent. The Psycho-Technical Directorate of RDSO, which is responsible for developing and administering these tests, has therefore decided to get developed an online portal for this. Computer Wing of RDSO, Lucknow has undertaken the project and designed & developed the online computer based psychometric test portal. This

paper details the development process of the Computerized Aptitude Test System (CATS), aimed at streamlining the testing & evaluation process for in-service safety category personnel.

2. Requirements and Challenges in the Existing System

2.1. Existing Testing Process

- Format: The psychometric tests for in-service personnel are currently administered in pen paper mode via physical test booklets and OMR answer sheets.
- Administration: Tests are conducted in groups (typically 30–40 candidates) under supervised conditions.
- **Evaluation:** Answers are manually scored and compiled based on predefined answer keys.

2.2. Identified Challenges

- Time-Consuming: Manual distribution, collection, and scoring delay results, thereby postponing decisions regarding promotions or re-deployment.
- Human Error: The manual evaluation process is susceptible to errors, including misinterpretation of answers and subjective biases.
- Delayed Feedback: Lack of immediate results prevents personnel from receiving timely feedback to address potential declines in cognitive performance.
- Environmental Impact: Extensive paper usage results in higher operational costs and contradicts sustainability goals.

3. System Design and Architecture

The proposed solution is an online CBT portal-Computerized Aptitude Test System (CATS)-that automates the entire process from test generation to result compilation. The key design objectives include security, scalability, real-time evaluation, and user-friendliness. The system is designed in a scalable manner so that it can accommodate different types of psycho metric tests conducted for different category of safety staff.

3.1. Technical Stack

- Front End: HTML, CSS, jQuery and Bootstrap are used to create a responsive and intuitive user interface.
- Back End: Django (Python) serves as the web framework, implementing the Model-View-Template (MVT) architecture.
- Database: PostgreSQL is used for reliable, scalable data storage.
- **Web Server:** Nginx is deployed to handle HTTP requests and serve static files.
- Security: AES-256 encryption is applied to all uploaded test batteries to ensure that only authorized users can access sensitive content.

3.2. Key Functionalities

- Test Battery Management: Administrator can create and upload multiple types of psychometric test batteries (e.g., Memory, Following Directions, Depth Perception, Perceptual Speed, Mechanical Comprehension).
- Randomized Test Generation: The system randomly selects questions from encrypted test batteries to generate unique test papers for each session.
- Role-Based Access Control (RBAC): Access is granted based on user roles; only authorized personnel (e.g., examiners, administrator, candidates) can access only the part of the system for which they have been permitted.
- **Demo Test Mode:** A demo test is available to familiarize users with the portal without exposing the actual test content.
- Two-Step Authentication: OTP based two step access control ensures secure access before commencing the examination.
- Automated Scoring and Reporting: Immediate scoring and result generation minimize delays in feedback.
- Image Capturing System: Provisions have been made to capture the image of candidates during candidate registration.

4. Implementation

4.1. Development Methodology

The development followed an iterative agile

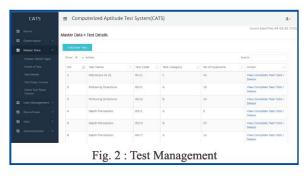
approach. Key phases included requirement analysis, system design, implementation, testing, and deployment. Frequent reviews by Psycho-Technical Directorate ensured that stakeholder requirements were met at each stage.

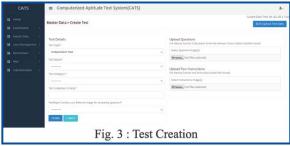
4.2. **System Modules**

- User Interface Module: Developed using Bootstrap and jQuery, ensuring compatibility across devices and ease of navigation.
- Test Management Module: Allows authorized



users to create, encrypt (using AES-256), and manage test batteries.





- **Examination Management Module:**
- Implements algorithms for automatic generation of psychometric test papers by randomizing test batteries, ensuring that each test session is unique.

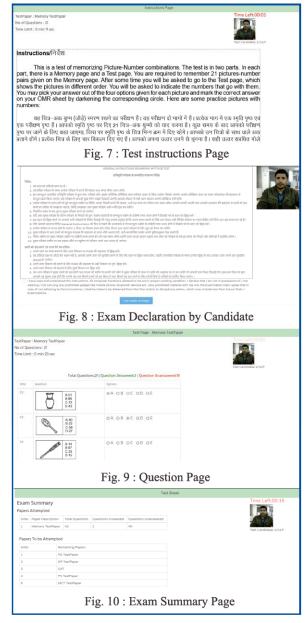


Fig. 4: Exam Creation



- Implementation of OTP based two-step authentication before start of examination
- Implements algorithm that randomizes the order of questions in each test batteries to minimize the risk of candidates sharing answers or peeking at each other's tests.
- Result Evaluation Module: Automates the scoring process by comparing submitted answers against an encrypted answer key, and generates detailed reports.
- Candidate's Module: This module enables the candidates to take the psychometric tests and submit responses.





5. Benefits of New System

The transition from a paper-based to a computerized testing system offers significant improvements:

- Efficiency Gains: Reduced administrative workload and faster result processing lead to quicker decision-making regarding promotions and re-deployments.
- Accuracy: Automated scoring minimizes errors associated with manual evaluation.
- Security: Encrypted test batteries and rolebased access control ensure that test integrity is maintained.
- Feedback and Continuous Improvement:
 Instant results allow personnel to identify weaknesses early and take corrective actions, such as additional training or medical interventions.
- Scalability and Sustainability: The online portal can be scaled to accommodate a large number of candidates and significantly reduces paper consumption.

6. Conclusion

The development of the Computerized Aptitude Test System (CATS) by Computer Wing, RDSO represents a crucial advancement in the psychometric evaluation of in-service safety personnel in Indian Railways. By automating test delivery, scoring, and reporting, the portal addresses many of the challenges associated with the traditional paper-based system. The implementation of modern web technologies and robust security measures not only enhances efficiency and accuracy but also provides timely feedback to ensure continuous mental fitness of the workforce. Ultimately, this system supports the Railways' commitment to maintaining high safety standards and operational efficiency in an increasingly complex and demanding environment.



Implementation of Energy Saving Scheme in 3-Phase Freight Electric Locomotives



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Abstract: Here, it has been discussed the implementation of an Energy Saving Scheme (ESS) in 3-phase freight electric locomotives (WAG-9 series). While regenerative braking already saves around 15% energy, further saving is possible by controlling auxiliary machines based on thermal demand. In the current system, these machines run even during idle conditions, leading to unnecessary power consumption. A modified load distribution scheme has been introduced to switch off non-essential auxiliaries when the locomotive is idle and no ventilation is needed. This scheme can save up to 140.4 kWh per loco per idle hour, resulting in approx. ₹28 lakhs/loco/year. With ~5400 locomotives, the projected annual saving is around ₹1600 crores, making this a significant energy-efficiency initiative.

सारांश: यहाँ 3Phase Freight Electric Locomotives (WAG—9 शृंखला) में Energy Saving Scheme (ESS) के कार्यान्वयन पर चर्चा की गई है। वर्तमान में regenerative braking से लगभग 15% ऊर्जा की बचत होती है, परंतु thermal demand के आधार पर auxiliary machines का नियंत्रण करके और अधिक ऊर्जा की बचत संभव है। वर्तमान प्रणाली में ये auxiliary machines idle condition (लोकोमोटिव खड़ा होने की स्थिति) में भी चलते रहते हैं, जिससे अनावश्यक विद्युत खपत होती है। प्रस्तावित संशोधित load distribution scheme के अनुसार, जब लोकोमोटिव idle हो और ventilation की आवश्यकता न हो, तब non-essential auxiliaries को स्वतः बंद किया जाएगा। यह योजना प्रति लोकोमोटिव प्रति idle घंटे में लगभग 140.4 kWh तक की बचत कर सकती है, जिससे सालाना प्रति लोकोमोटिव लगभग ₹30 लाख की बचत संभव है। लगभग 5400 locomotives के मौजूदा बेड़े के आधार पर, अनुमानित वार्षिक बचत ₹1600 करोड़ तक हो सकती है। यह योजना रेलवे संचालन में ऊर्जा दक्षता लाने की दिशा में एक महत्वपूर्ण पहल है।

1.0 Introduction

Presently, 3-Phase freight locomotives i.e. WAG-9/WAG9H/WAG9HC are being produced by CLW & BLW. These locos have unique feature of regeneration of energy. The national figure of saving on account of regeneration is around 15 percent.

It has been observed that there is further scope of saving of electrical energy by turning on/off the auxiliary machines as per requirement. There are three auxiliary converters provided in 3-Phase locomotives which supply power to 13 Nos. auxiliary machines fitted in these locos for various functions like cooling of traction motor blower, Oil cooler blower, scavenger blower, compressors, pumps, battery charger etc.

The duty cycle of freight locomotive in India is about 50 percent that means for 50 percent of time the locomotive is working i.e. locomotive is in motion and tractive or braking efforts are being applied and in the rest of time locomotive

remains idle that means the locomotive is under preparation of load, either it is idling in the yard, creating pressure on a rake, it is connected with the load and loading is in progress, TXR examination, GDR checking by loco pilots & guards or else waiting for line clear in a siding or en-route or waiting in a section for precedence of Mail/Express trains or waiting in a station for changing of Crews. In all the above conditions locomotive remains idle i.e. locomotive is not moving (Zero Speed) and no tractive/braking effort is being applied i.e. throttle is zero.

It is seen that in this condition all the TMB, TMS & OCBs are running even there is no load in the corresponding equipment for which blowers are provided to cool that equipment. There is no load in traction motor and transformer. There is no need to run the blower for transformer oil cooler & Traction motor. As traction motor blowers are not running so there is no need to run scavenger motor of traction motor blower.

2.0 Present Scheme

Loads of auxiliary machines are being taken by

auxiliary converters as given in the following table.

Auxiliary	Auxiliary loads	Frequency
Converter		(Normal Mode)
BUR 1 supply	• Oil Cooler Blower – 1&2 (OCB – 1&2)	44 Hz, 50 Hz
BUR 2 supply	• Traction Motor Blower –1&2 (TMB – 1&2)	50 Hz
	• Transformer Oil Pump – 1&2 (TFP MPH – 1&2)	
	• Traction Converter Oil Pump – 1&2 (SR MPH – 1&2)	
BUR 3 supply	• Scavenge blowers – 1&2 (ScTMB – 1&2)	50 Hz
	• Main compressor – 1&2 (MCP – 1&2)	
	Battery charger (CHBA)	

The most energy consuming blowers are OCB – 1&2 and TMB -1&2 (rating of OCB is 30 KW and TMB is 25 KW). The rating of GTO based auxiliary converter is 100 KVA and IGBT based auxiliary converter is 130 KVA. OCB – 1&2 is connected with BUR1. OCB motor runs on ventilation demand which depends on temperature level of transformer oil as per CLW manual. Below 47 deg. Celsius, there is no ventilation demand and OCB does not work. There are three ventilation levels depending upon the transformer oil temperature – Level-1 (47-50 Deg. C), Level-2 (52-55 Deg. C) and Level-3 (57-60 Deg. C and above). OCB starts running whenever the oil temperature exceeds 47 deg. irrespective of working of locomotive i.e. whether locomotive remains idle or in running [idle means locomotive is in standing condition, throttle (Tractive effort/braking effort) is Zero].

In the present system as per design configuration, TMB -1&2 (25KW each) and ScTMB -1&2 (3 KW each) is connected with

BUR2 and BUR3 respectively. As soon as loco energies, BUR2 and BUR3 start working, therefore, TMB & ScTMB start working irrespective of ventilation demand. The ventilation demand in 3-phase locomotive totally depends upon temperature level of traction motor, converter oil & transformer oil. But in the present case, the traction motor blower and its scavenger blowers are running continuously irrespective of ventilation demand.

3.0 Proposed Modification

Auxiliary loads have been re-distributed among auxiliary converters in which ScTMB and Cab AC Unit has been removed from BUR-3 and added to BUR-2. Further, MRB and its Scavenge have been added to BUR-3 as mentioned in Para-2.5 above. Rest of the load distributions remains same. The distribution of load among the auxiliary converters in normal condition are detailed below. These modifications have been proposed and Modification Sheet No. RDSO/2020/EL/MS/0482 (Rev. 1) dtd. 10.04.2024 has been issued.

Auxiliary Converter	Existing Load Distribution	Modified Load Distribution	
BUR 1 supply	OCB – 1&2	OCB – 1&2	
BUR 2 supply	TMB – 1&2	TMB – 1&2	
	TFP MPH – 1&2	ScTMB – 1&2	
	SR Pump – 1&2	TFP MPH – 1&2	
	Cab AC Unit - 1&2	SR Pump – 1&2	
BUR 3 supply	CP – 1&2	CP – 1&2	
	ScTMB – 1&2	Battery charger	
	Battery charger	MR Blower – 1&2	
		Scavenge to MRB – 1&2	
		Cab AC Unit – 1&2	

4.0

Monetary Saving Calculation Load Distribution in Normal Mode:

Condition	Contacto	r Position	n Load shared by					
	CLOSE	OPEN	BU	R-1	BUR-	-2	BU	R-3
			EQPT.	LOAD	EQPT.	LOAD	EQPT.	LOAD
	52/3	52/2	OCB - 1&2	60 KW	TMB-1&2	50 KW	CP-1&2	30KW
	52.4/2	52/4	162					
	52.5/1	52.4/1			MPH-1&2	9.4 KW	Battery	12 KW
All BURs	52/1	52.5/2			SR Pump- 1&2	5 KW	Charger	
OK	52/5				ScTMB-1&2	6 KW	MRB – 1&2	5.4 KW
							ScMRB -1&2	1.5 KW
							AC-1&2	4 KW
	To	otal Power		60 KW		70.4 KW	52.9	9 KW

II. Load when Energy Saving Mode (ESM) is active:

Condition	Contacto	r Position			Load shared by			
	CLOSE	OPEN	BU	R-1	BUF	R-2	BUI	₹-3
			EQPT.	LOAD	EQPT.	LOAD	EQPT.	LOAD
	52/3	52/2	Nil	Nil	MPH-1&2	9.4 KW	CP-1&2	30KW
	52.4/2	52/4						
All BURs	52.5/1	52.4/1			SR Pump- 1&2	5 KW	Battery Charger	12 KW
OK		52.5/2			AC	3 KW		
		52/1*						
		52/5*						
	To	tal Power		Nil		Nil	42.	9 KW

III. Energy Saving Calculation

Max. Power consumed by Aux. loads when ESM is not active = (60KW + 70.4KW + 52.9 KW)

=183.3 KW

Max. Power consumed by Aux. loads when ESM is active = 42.9 KW

Difference in power consumed when ESM is active = (183.3-42.9) KW = 130.4 KW

In view of above, Energy saved when ESM is active for 1 hour = 140.4 KWH

Taking electricity rate as Rs. 6 per unit and 12 hrs idle of freight loco in one day and loco is

energized for 300 days in a year

Saving/loco/annum = $(140.4 \text{kw} \times 12 \text{hrs} \times 300 \text{days} \times \text{Rs.} 6)$

=Around Rs. 30 lacs

5.0 Outcome:

There are population of existing fleet of WAG9/WAG9H locomotives is around 5400 numbers. Taking this, saving comes out to be approx. **Rs. 1600 crores per annum** in traction bill which will be a considerable saving on this account.



Development of Auto-Transformer Neutral Current Ratio Based Automatic Fault Locator for 2X25 kV AC Traction System



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Abstract: Indian Railways has completed 100 years of Electrification since 1925. Indian Railway has electrified more than 94% of its total large line network, covering 62119 route kilometers out of the total broad-gauge network (65,775 RKMs) of Indian Railways with a 1x25KV traction power system.

In the last decade of the 20th Century, a 2X25 kV traction power supply system was introduced in the limited section Bilaspur-Katni-Bina section of Indian Railways.

Now, Indian Railways will convert 1x25 kV traction power supply systems into 2x25 kV traction power supply systems. Autotransformers at regular intervalsalong the line (generally at TSS, SSP & SP) are provided in a 2x25 kV traction power supply system. Distance protection relays cannot be used to locate ground faults in $2\times25 \text{ kV}$ traction power supply systems because the ratio between reactance (impedance) and distance to the fault point is not linear in a $2\times25 \text{ kV}$ traction power supply system, unlike in a $1\times25 \text{ kV}$ traction power system. Thus, the task of locating the ground fault in a 2x25 kV traction power System becomes a complicated task. The method described here allows the location of a ground fault accurately in real-time, using the modules for measuring the neutral current in different autotransformers when the ground fault occurs.

सारांश: भारतीय रेलवे ने 1925 से विद्युतकरण के 100 वर्ष पूरे कर लिए हैं। भारतीय रेलवे ने अपने कुल बड़े रेल नेटवर्क का 94% से अधिक विद्युत्कृत किया है, जो भारतीय रेलवे के कुल चौड़े गेज नेटवर्क (65,775 आरकेएम) में से 62,119 मार्ग किलोमीटर कवर करता है, जिसमें 1x25 KV ट्रैक्शन पावर सिस्टम शामिल है। 20वीं सदी के पिछले दशक में, भारतीय रेलवे के सीमित खंड बिलासपुर—कटनी—बीना खंड में 2x25 kV ट्रैक्शन पावर सप्लाई सिस्टम को पेश किया गया था।

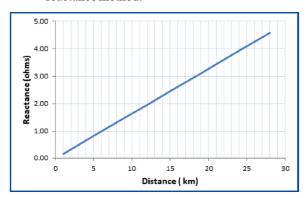
अब, भारतीय रेलवे 1x25 कवीय ट्रैक्शन पावर सप्लाई सिस्टम को 2x25 KV ट्रैक्शन पावर सप्लाई सिस्टम में परिवर्तित करेगा। 2x25 KV ट्रैक्शन पावर सप्लाई सिस्टम में लाइन के साथ नियमित अंतराल पर ऑटो ट्रांसफार्मर (आमतौर पर TSS, SSP और SP पर) उपलब्ध होते हैं। ग्राउंड फॉल्ट्स को 2x25 ज्ञट ट्रैक्शन पावर सप्लाई सिस्टम में स्थान निर्घारित करने के लिए उस्टेंस प्रोटेक्शन रिलेज का उपयोग नहीं किया जा सकता क्यों कि 2x25 KV ट्रैक्शन पावर सप्लाई सिस्टम में रिएक्टेंस (इम्पीडेंस) और फॉल्ट पॉइंट के बीच की दूरी का अनुपात रेखीय नहीं होता है, जबिक 1x25 KV ट्रैक्शन पावर सिस्टम में ऐसा होता है। इसलिए, 2x25 KV ट्रैक्शन पावर सिस्टम में ग्राउंड फॉल्ट को स्थान निर्घारित करने का कार्य जटिल बन जाता है। यहाँ वर्णित विधि ग्राउंड फॉल्ट होने पर विभिन्न ऑटो ट्रांसफार्मरों में न्यूट्रल करंट को मापने के लिए मॉड्यूल का उपयोग करके वास्तविक समय में ग्राउंड फॉल्ट को सटीकता से निर्घारित करने की अनुमति देती है।

1. Scope:

Indian Railway will convert a 1x25kV traction power supply system into a 2x25kV traction power supply system to feed high-speed trains under Mission Raftaar. The 2x25 kV system, as compared to the traditional 1×25 kV traction system, permits the required number of traction substations erected along the line to be reduced because it has lower losses, and lower voltage drops along the line. In a 2×25 kV system, generally, each traction substationfeeds two sectors, one in each direction. Each sector consists of several subsections of similar length that are delimited by an autotransformer at TSS,

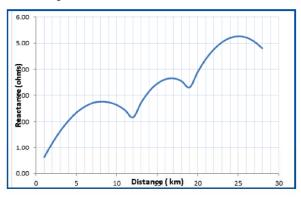
SSP & SP. These auto transformers have three terminals; 1st is connected to the positive conductor at a rated voltage of 25 kV (traction), 2nd is connected to the negative conductor, also rated 25 kV (feeder), and 3rd i.e.,the midpoint of its winding, is connected to the rail and ground. Electrical installations need adequate protection to ensure reliable and safe operation. This need is accentuated in the case of electric railway traction systems due to the increased number of failures caused by the sliding of the pantograph on the contact wire, which can cause its breakage. These faults cause severe economic and social problems by disrupting rail services.

Therefore, it is important to locate the point of the ground fault that has occurred and isolate the faulty subsection. In the 1X25kV traction power supply system, the most-used method for measuring the distance from a traction substation to a ground fault due to its stability, reliability, and simplicity is the impedance/reactance method.



OHE Impedance – Distance Characteristics in 25kV Traction System

However, in a 2×25 kV traction power system, it is impossible to determine the distance from the traction substation to the ground faults acceptably with this method. This is due to the presence of autotransformers that make the impedance-distance ratio nonlinear.



OHE Impedance – Distance characteristics in 2X25kV Traction System

Amethod of compensation using the neutral current of the adjacent autotransformers of the faulty sector, this ground fault location method allows the location where a ground fault has occurred in real-time, and whether it has occurred in the catenary (positive conductor) or feeder (negative conductor) as well.

2. Objectives:

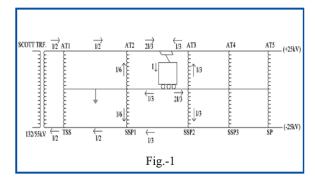
The main objective of the Automatic Fault Locator systems for the 2X25 kV AC Traction System is given below:

- a. To identify the fault (Traction to earth, feeder to earth, Traction to feeder).
- To locate fault point within the accuracy of +/500 meter for traction to earth and feeder to earth
 fault and +/- 1000 meter for traction to feeder
 fault.

3. Methodology:

 i. Brief Description of Ground Fault Identification Method for 2×25 kV Railway Power Supply Systems:

Figure 1 below shows the simplified scheme of an electric section fed by a 2×25 kV power system with four subsections delimited by intermediate autotransformers. Also, the current distribution in the conductors (+25kV Traction and -25kV Feeder) is represented when a train travels in the intermediate section. When in theline of a 2×25 kV traction power supply system, a fault occurs between the catenary and rail or between the feeder and rail, there is a significant increase in the current flowing in the windings of the closest autotransformers to the position where the fault has occurred. In addition, the angles between these neutral currents of autotransformers and the voltage between the catenary and rail change at the location of the autotransformers.



ii. Method for Ground Fault Location in 2×25 kV Traction Power Systems:

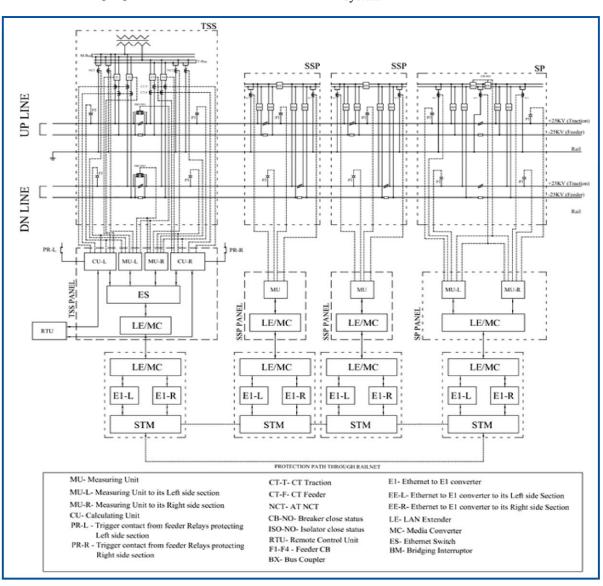
a. Voltages, neutral currents, and the phase angle in the different autotransformers should be measured. In the case of a ground fault, the neutral current in autotransformers adjacent to either side of the fault would be maximum compared to other autotransformers in the section, and the Fault locator system activates on sensing the maximum current compared by the system.

- b. The subsection between autotransformers and the positive or negative conductor where the fault has occurred is identified by analysing the phase angle between the voltages and neutral currents in the autotransformers.
- c. The fault location is performed by a comparison of the current measured in the two adjacent autotransformers by the formula given below:

$$\begin{array}{c} Ln+1-Ln \\ L=Ln+----\{(100\,x\,In+1\,/\,In+\,\,In\,\,+1)-Q1\} \\ 100-Q1-Q2 \end{array}$$

where:

- L Kilometrage of the fault point from the starting station.
- Ln Kilometrage of ATn interposing the fault point
- Ln+1 Kilometrage of ATn+1 interposing the fault point
- In Indicated current value of ATn
- In +1 Indicated current value of ATn+1
- Q1,Q2 Constants determining the shape of the location curve (this factor shall be separately settable for traction to earth fault and feeder to earth fault).
- iii. Configuration of the Automatic Fault Locator system



4. Salient Feature of the Automatic Fault Locator:

- The measuring unit (MU)&calculating unit (CU) of the automatic fault locatorare flush mounting/draw out type. The enclosure class of the module is IP 52 or better as per IEC 60529.
- ii. The current coils are capable of withstanding 4In continuously, and the short-time rating is 100In for 1 sec. where 'In' is rated current. The voltage coil is capable of withstanding 1.15 times the rated voltage continuously and 1.5 times for 10 seconds.
- iii. Electro-magnetic interference immunity is provided in MU & CU.
- iv. CU has the facility to record at least 20 latest trigger Records and 2000 Events.
- Self-diagnostic features and displays confirm the module's healthiness or defects. MU monitors the ON/OFF status of ATs, CB, and CT failures of all AT neutral CTs connected in the unit.
- vi. CU can communicate with the RTU based on IEC 60870-5-103 and IEC 61850 protocols for transfer of information stored in CU i.e., fault distance along with, type of fault with date and time stamping, failure of AT's neutral CT, communication fail, MU fail, CU fail to the RTU for transferring to RCC.
- vii. Password protection to avoid unauthorized changes in the settings in CU & MU.
- viii. The accuracy of the Automatic fault locator for Traction to Earth and Feeder to Earth faults within +/-500meters and traction to feeder faults shall not be more than +/-1000 meter.

5. Present status:

i. Automatic Fault locator for 2X25KV AC

- traction has been developed indigenously by M/s ALIND, Thiruvananthapuram, and installed at Anuppur-Shahdol section in Bilaspur Division of SECR for trial.
- ii. RDSO has issued the revised Specification No. TI/SPC/PSI/AFL/0240 for Auto Transformer Neutral Current ratio based Automatic Fault Locator for 2X25 kV AC Traction System to Zonal Railways in January 2025 for necessary action.
- iii. The STR for AFL for the development of vendors is in process and will be mapped in UVAM after its finalization.

6. References:

- i RDSO Specification No. ETI/PSI/135(8/89)- AT Boost up current ratio type fault locator for OHE for 2x25 kV AT Feeding System.
- ii RDSO Specification No. TI/SPC/ PSI/ AFL/0240- Auto-transformer Neutral Current Ratio Based Automatic Fault Locator for 2x25 kVAC Traction System.
- iii International Electrotechnical Commission (IEC)- IEC 60870-5—103 and IEC 61850 for communication protocol between AFL and RTU.
- iv RDSO Specification No. TI/SPC/ PSI/ PROTCT/7101- Technical Specification for Control & Relay Panel Including Numerical type protection relays for Scott- connected /V Connected Single Phase Traction Transformers, OHE Protection, 55kV AT Protection & Shunt Capacitor Bank protection for 2 X 25 kV Traction Sub Station, Sectioning and Paralleling Post, Sub-Sectioning & paralleling Post and Autotransformer Post.



Proof of Concept Trials for Autonomous Thermal Vision Camera Based Loco Pilot Assistance System (ATLAS) to avoid Elephant –Train Collision



Neeraj Kumar Dy. Director/MP RDSO, Lucknow



Pramod Kumar Vishwakarma

JE/D/MP

RDSO, Lucknow

Abstract: To alert the crew of passage of big wild animals such as Elephants to avoid the train elephant collision, there should be systems on-board of the locomotive, which can detect the Elephant and generate the audio visual alert autonomously much before the naked eye visibility even in night time using Artificial Intelligence. With the advancements in artificial Intelligence, computer vision is becoming more capable of detecting and identifying objects, face recognition etc. Images taken by thermal camera can be processed through Computer vision technology to detect elephants. This article is giving insight on the effort done by RDSO, Motive Power Directorate as Proof of concept trials with on-board LWIR Thermal Vision Camera having feature of Artificial Intelligence to prevent train—elephant collision.

सारांश : रेलवे ट्रैक पर हाथियों जैसे बड़े वन्यजीवों की मौजूदगी से होने वाली दुर्घटनाओं को रोकने के लिए, ट्रेन में ऐसे सिस्टम होने चाहिए जो हाथी को समय रहते पहचान सकें और चालक दल को श्रव्य—दृश्य चेतावनी के जरिए सतर्क कर सकें कृ खासकर रात के समय या कम दृश्यता में, जब आंखों से दूर देखना संभव नहीं होता।

आज के समय में आर्टिफिशियल इंटेलिजेंस (AI) और कंप्यूटर विजन जैसी तकनीकें बहुत आगे बढ़ चुकी हैं, जो तस्वीरों के जिरए किसी भी चीज को पहचान सकती हैं। थर्मल कैमरों से ली गई तस्वीरों का उपयोग करके कंप्यूटर विजन के जिरए हाथी की पहचान की जा सकती है।

यह लेख RDSO, Motive Power Directorate द्वारा किए गए परीक्षण (Proof of Concept) पर आधारित है, जिसमें ट्रेन में LWIR थर्मल कैमरा और AI तकनीक को जोड़कर यह दिखाया गया कि हम ट्रेन—हाथी टक्कर की घटनाओं को कैसे रोक सकते हैं।

1. Introduction

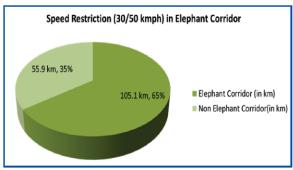
India is home to approx. 30000 Elephants (About 60% of all Asian Elephants). To preserve the Elephants, total of 33 Elephant Reserve have been notified in the country with the area of 80777.778 Sq.km with purpose of protecting elephants, their habitat & corridors and addressing the issues of man-animal conflict.

Indian Railways are also sensitive to Wild life protections and for the moving trains passing through Forest Corridor, Speed Restriction is imposed on such elephant corridor. Eg. in the Elephant Corridor APDJ-SGUJ section of NF Railway, speed restriction is followed to avoid hitting of wild animals with moving trains.

However, there have been many incidents of collisions of elephants by trains in forest areas. Train-elephant collision has been a serious cause of concern for the Indian Railways. The figure of

elephant deaths in India due to train hits from 2009-10 to 2020-21 is given below.

A case is also filed against the loco pilots and booked under Section 9 of Wild life Protection Act by Forest Department in case of death of elephants- who were killed by a moving train.

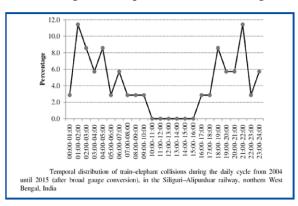


It is observed that the train-elephant collision happens during dawn, dusk and night as Dark color animal can not be seen during

State	No. of Deaths
Assam	62
West Bengal	57
Odisha	27
Uttarakhand	14
Kerala	9
Jharkhand	7
Tamil Nadu	5
Karnataka	3
Tripura	1
U.P	1
Total	**186**

night/darkness. The pattern of train-elephant collision in Silliguri-Alipurduar Railway is furnished below for reference.

Hence, it has been felt that there should be systems on-board of the locomotive, which can detect the Elephant and generate the audio visual alert autonomously much before the naked eye visibility even in night time using Artificial Intelligence. With the advancements in artificial Intelligence, computer vision is becoming more



capable of detecting and identifying objects, face recognition etc. Images taken by thermal camera can be processed through Computer vision technology to detect elephants.

In view of the above, Thermal Vision Camera System has been developed to alert the crew of the passage of big wild animals. The system mainly consists of Thermal Camera (LWIR), Display & Processing Electronics Unit. The system uses artificial Intelligence for autonomous recognition of adult elephants on track in almost real-time to avoid loco collision

with wild animals on track by pre-warning the loco pilot sufficiently in advance by generating an audio-visual alarm. The use of a Thermal Camera greatly enhances the range of visibility during day/night conditions for warm-blooded animals. The system also records and stores the video for at least one-week duration.

- 1 Technical details of Thermal Vision Camera System
- 2 Main features of the Thermal Vision Camera System

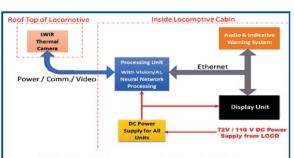
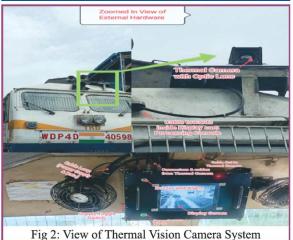


Fig. 1: Block Diagrammatic Electrical Schema of Thermal Vision Camera



 SN
 Feature
 Description

 1
 Technology used least 60Hz refresh rate (640x512) VGA

 2
 Display Screen Size
 10.4"Display Unit (1024x768) XGA

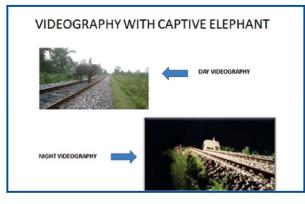
 3
 Control Unit Processing unit with Vision processing, AI and Neural Networks

SN	Feature	Description
4	Power Supply	72/110 V DC power supply from a locomotive
5	Protection level	IP 65

3 Training and Testing for Development of AI algorithm for autonomous detection of Elephant

A domesticated elephant was kept near the railway track to imitate real-time scenarios and the loco fitted with the TVC system was made to run to and fro to capture different orientations of the elephant while maintaining a safe distance from the elephant (100m) during day and night.

Sufficient data were collected to develop the learning of the system for the autonomous detection of an adult Elephant.



Unique image frames of Elephant(s) were extracted from the recorded videos. The training of the model over Convolution Neural Network was carried out.

These unique image frames has been annotated as POSITIVE object (i.e. Elephant(s)).



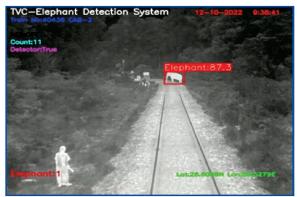


After training, the model is tested with images of elephant in different orientations.



Deployment of AI model with Thermal Vision Camera System and Functional Trials in real time on Railway Track

During the trial, a domesticated elephant was kept near the railway track. Loco fitted with a fully functional TVC system was made to run and whenever an elephant was detected an alert alarm was raised and the display device shows a red box around the elephant.



4.1 Methodology of Functional Trials

Domesticated Elephant was provided by Forest Department. The Elephant was placed on the track/beside the track in different orientation and Loco was moved from distance more than 700 mtr. with slow speed and stopped well before the Elephant. The autonomous detection through the system noted and recorded by the system. The process continued during the trials. Based on the recorded data, False Alarm, Elephant Detection calculated through Confusion Matrix.

4.1.1 Section and timings for trials

Frequent elephant sighting is pre requirement for testing our installed system. Availability of track with 01 Km of Line of Sight (LoS) was also required. The sighting of wild elephants was unpredictable and also to check the feasibility of the system the availability of domesticated elephant was required throughout the execution of trials. Trials were conducted in morning, evening, day and night conditions.

4.1.2 Parameters measured during the trials

Visibility of targets through System: During dynamic trials, Visibility has been evaluated based on the visibility of Semaphore Signal Post (representing Metallic Materials), LC Building (representing concrete structure) and Human/Animal.

Generation of Audio Visual Alarm: During trials, generation of Audio Visual Alarm upon detection / recognition of Captive / Wild Elephant on the track along with rectangular annotation on the display was checked.

Event recording: Event recording with Train ID and Cab No., Date and time stampings, No. of elephants detected, GPS data(Lat/Long Position).

Data Extraction: Data extraction in USB Drive.

4.1.3 Collection of Data:

Dynamic Trials: Several runs were conducted at various speed and with different orientation of elephant to cover almost all aspect of possible detection.

Various types of dynamic trials were conducted to ensure following analysis:

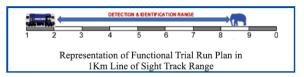
1. Analysis of False Alarm Rate (FAR)

- Travel the Loco.
- Observe the real time thermal video on TVC Display Console for false alarm, if any.

 The thermal video so recorded by the TVC System shall be extracted out of the system for analysis of FAR through Confusion Matrix.

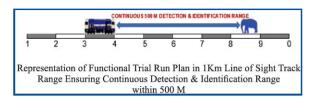
2. Elephant Recognition Range of 500 m

 Move the Loco towards Domesticated Elephant(s) in such a way so as to pin point the accurate range of autonomous Detection & Identification of Elephant(s) reported by TVC System on adequate speed. The thermal video recorded by TVC System.



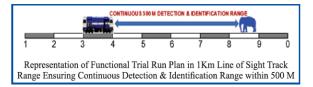
3. Elephant Recognition continuously within Range of 500 m

- Distance between Loco & Elephant(s) has been maintained @ 500 m.
- Move the Loco towards Domesticated Elephant(s) in such a way so as to observe the autonomous Detection & Identification of Elephant(s) reported by TVC System shall be continuous within 500 m.



Static Trials: Loco fitted with TVC system is stood at pre-defined location while the elephant was present at far distance. Different orientation of elephants is recorded for learning purpose for autonomous detection.

- Distance between Loco & Elephant(s) has been maintained at 500 m.
- However, the Elephant(s) shall be asked for dynamic movements at its position for capturing different orientation of elephant.



4.2 Visuals from the TVC system during day/night time of trials

The sample visuals capturing the target in different time of day i.e. Clear (Day and Night), is given below.

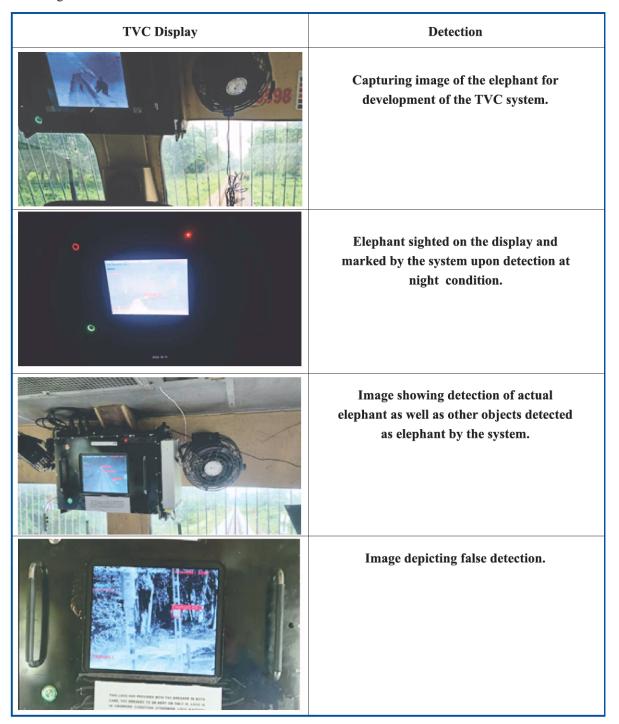


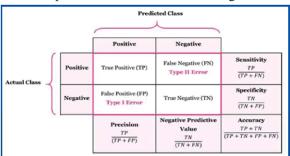
Fig: Visuals of TVC system for different detection level during trials

4.3 Assessment Criteria

Thermal videos so recorded used to prepare the Analysis Report via Confusion Matrix data.

4.3.1 Confusion Matrix

The object identification, heavily depends on the number of object images with different orientation, distance, atmospheric condition, movement direction, movement speed etc. used for Neural Network training. The trained "object model", is then used for identification either from images, or live video. Depending on the "model-value", the system can identify object correctly, with stating "confidence-value" of identification. But, at certain times the other object (not the real one) is also identified as object in concern. This leads to confusion. A confusion matrix is a technique for summarizing the performance of a classification algorithm.



True Positive Rate/Recall/Sensitivity = TP/ (TP+FN)

Recall = (Number of true positive predictions) / (Number of actual positive instances)

Precision/Positive Predictive Value = TP/(TP+FP)

Precision = (Number of true positive predictions)/(Number of positive predictions)

Specificity=TN/(TN+FP)

Specificity = (Number of true negative predictions) / (Number of actual negative instances)

Negative Predictive Value=TN/(TN+FN)

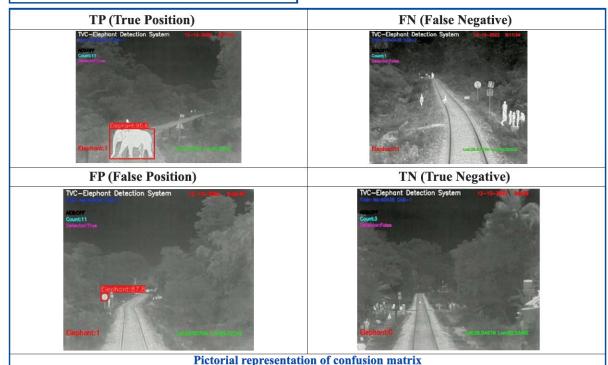
NPV = (Number of true negative predictions) / (Number of negative predictions)

Accuracy=(TP+TN)/(TP+TN+FP+FN)

Accuracy = (Number of correct predictions) / (Total number of predictions)

Considered Two Classes of data set (i.e. images) while training of AI/ML S/w model:

- a) Elephant (POSITIVE)
- b) Other-Object (NEGATIVE)



4.3.2 Data Analysis

- Image frames of Elephant(s) during functional trials has been extracted from the recorded videos
- These image frames have been segregated as TP,TN, FP, FN based on annotation done on the image by the system in the recorded video.
- The count of TP, TN, FP, FN were arranged in Confusion matrix and overall performance metrics calculated by evenly distributing Actual Positive counts and Actual Negative Counts.
- To calculate the True Positive Rate for the Elephant for distance at 500 mtr., Elephant Images extracted from TVC recorded video have been segregated where the Elephant were at a distance of 500 mtr-600 mtr. from the loco, when loco is moving towards Elephants. These images annotation were segregated for False Negative counts and True Positive counts. Based on the above, True Positive rate was calculated. The True Positive rate should be 75% minimum for minimum 60 samples

4.4 Data Presentation and Analysis

The data analysis based on the assessment criteria as illustrated at Para 4.3 is furnished below.

		Predicted		
		Positive	Negative	Total
ctual	Positive	86%	14%	100%
Act	Negative	30%	70%	100%

Actual Frame for trials with elephant during dynamic condition

% indicated above is the total of Actual Positive Images and Actual Negative Images respectively.

- Performance Metrics
- Normalization

Recall	Precision	F1 Score	Accuracy
85.86%	68.80%	76.39%	77.07%

The Positive and Negative counts are not equal.

So, The Negative Data is normalized as such it should be equal to Positive data.

• Performance Metrics after Normalization From the data, it is observed that precision is

Recall	Precision	F1 Score	Accuracy
85.86%	74.36%	79.70%	78.13%

74.36%. It indicates there are false alarm generated with system is 25.64% (approx. 26%) of total detection by the system. Based on the outcome of functional trials, the system was put on field trials for further capturing of video in real time scenario and performance feedback from the crew. As the system is using AI algorithm, additional video helps to train the AI model to reduce the False Alarm and further improve the metrics.

Further, after improvisation of the system, the False alarm rate was analysed with collected video and reduced significantly, which has been corroborated with the feedback obtained from North Frontier Railways.

4.5 Basis of evaluation:

However, the system has been evaluated based on the criteria of success rate of detection of Elephant ie. True Positive rate (Recall) for the Elephant at various distance as tabulated below.

Distance of Elephant in Mtr. from Loco	True Positive Rate
<500	98.21%
500-600	85.41%
>600	52.79%

5 Conclusion

Based on the functional trials and improvisation of the system, the system is able to detect and recognize wild animals considerably even during dusk/night as well as during day time.

Further improvisation of the AI Model is a continual process. Based on the experience gained with Proof of concept trials, the BIS Standard for Autonomous Thermal Vision Camera based Loco Pilot Assistance System (ATLAS) bearing no. IS/RDSO-MP/0001: 2023

has been issued by RDSO, Motive Power Directorate.

6 System Limitation

- The IR camera works on line of sight technology.
 Hence it doesn't provide visibility aligning with the track at curves.
- (ii) The system utility is tested and verified during clear day/night time. The system performance may degrade in Rain, fog and other harsh environment.

7 Futuristic development

Following futuristic development may yield further benefit.

- (i) Provision of swiveling mechanism for thermal camera, which can align the line of sight of camera with the track while negotiating the curve.
- (ii) System initiated Braking triggered by autonomous detection of the wild animal.

- (iii) Integration of GIS data available with the Fog safe device into the TVC system for identification of signal posts, sign boards ahead of the track.
- (iv) AI learning of the system can be extended to identify other class of objects such as cattle, human etc.
- (v) Wayside solution required on Blind-Curves which can be integrated with the onboard system by streaming the live feed from the wayside camera to the onboard system via 5g or RF technology.
- (vi) Autonomous learning and up-gradation of the ML algorithm via cloud.

8 Courtesy and credits for the Trials

- Officials, and Elephants of Forest Departments BUXA reserve
- Officials of Alipurduar Division (NFR)
- Team of RDSO, Motive Power Directorate



Examining EQ and IQ Through The Theory of Mind



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Abstract: This article explores the interplay between Emotional Intelligence (EQ) and Intelligence Quotient (IQ) and their impact on personal and professional success. EQ, encompassing self-awareness, self-regulation, motivation, empathy, and social skills, plays a crucial role in effective communication and leadership. Various models of EQ, such as the Ability Model and Mixed Model, highlight its cognitive and behavioral aspects. Similarly, multiple theories of IQ, including Spearman's Two-Factor Theory and Gardner's Multiple Intelligences, offer diverse perspectives on cognitive abilities. The article emphasizes the need for balancing both EQ and IQ for holistic success, suggesting strategies for their development through mindfulness, learning, and social engagement.

सारांश: यह लेख भावनात्मक बुद्धिमता (EQ) और बौद्धिक बुद्धिमता (IQ) के परस्पर संबंध और उनके व्यक्तिगत व व्यावसायिक सफलता पर प्रमाव का विश्लेषण करता है। EQ, जिसमें आत्म—जागरूकता, आत्म—नियंत्रण, प्रेरणा, सहानुभूति और सामाजिक कौशल शामिल हैं, प्रभावी संचार और नेतृत्व में महत्वपूर्ण भूमिका निभाता है। EQ के विभिन्न मॉडल, जैसे एबिलिटी मॉडल और मिक्स्ड मॉडल, इसकी संज्ञानात्मक और व्यवहारिक विशेषताओं को उजागर करते हैं। इसी तरह, प्फ के विभिन्न सिद्धांत, जैसे स्पीयरमैन का टू—फैक्टर थ्योरी और गार्डनर का मल्टीपल इंटेलिजेंस सिद्धांत, संज्ञानात्मक क्षमताओं के विविध दृष्टिकोण प्रस्तुत करते हैं। प्रस्तुत लेख में EQ और IQ के संतुलन को समग्र सफलता के लिए आवश्यक माना गया है तथा ध्यान, सीखने और सामाजिक सहभागिता के माध्यम से उनके विकास के उपाय सुझाए गए हैं।

Emotional Intelligence (EQ), often referred to as emotional quotient, is a critical aspect of human behaviour that encompasses the ability to understand, manage, and utilize emotions effectively in ourselves and others. Unlike traditional intelligence (IQ), which measures cognitive abilities, EQ focuses on emotional and social skills, playing a vital role in our personal and professional lives.

EQ consists of five key components: self-awareness, self-regulation, motivation, empathy, and social skills.

Self-awareness is the ability to recognize and understand one's emotions, strengths, weaknesses, and values. Individuals with high self-awareness can assess how their feelings affect their thoughts and behaviour, leading to better decision-making.

Self-regulation involves managing one's emotions in a healthy manner, allowing for adaptability and control in challenging situations. People with strong self-regulation

can think before acting, remain calm under pressure, and express their emotions appropriately, fostering a constructive environment.

Motivation refers to the intrinsic drive to pursue goals for personal satisfaction rather than external rewards. Individuals with high EQ are often more resilient, passionate, and committed to their objectives, which can lead to greater achievements and fulfilment.

Empathy, a cornerstone of emotional intelligence, is the ability to understand and share the feelings of others. Empathetic individuals can identify emotional cues and respond appropriately, building strong relationships and effective communication. This skill is particularly important in leadership roles, where understanding team dynamics and individual needs can significantly influence performance and morale.

Finally, social skills encompass the ability to interact well with others, manage conflict, and

inspire or influence people. Those with strong social skills are often effective leaders, capable of fostering collaboration and teamwork.

The importance of EQ has gained recognition in various fields, particularly in business, education, and mental health. Research shows that individuals with high emotional intelligence tend to perform better in the workplace, have stronger relationships, and experience better mental health. In leadership, EQ is crucial for motivating teams, fostering a positive culture, and navigating complex interpersonal dynamics. Emotional intelligence is not just an innate trait but a skill that can be developed over time. Enhancing one's EQ can lead to improved relationships, greater professional success, and a more fulfilling life. As we continue to navigate an increasingly complex world, the importance of emotional intelligence becomes more apparent, making it an essential aspect of personal and professional development.

Theories and Models of Emotional Intelligence

Researchers in the field of Emotional Intelligence (EI) have categorized their findings into two primary frameworks, the ability model and the mixed model.

Ability Model of Emotional Intelligence

The ability model frames emotional intelligence in a manner similar to traditional cognitive intelligence. Developed by Salovey and Mayer in 1990, this model posits that emotional intelligence develops over time, correlates with IQ measures, and can be assessed through performance-based tests (Rosete & Ciarrochi, 2005). This model also legitimizes emotional intelligence within educational and organizational contexts, where emotions significantly influence relationship dynamics. However, while emotional intelligence can predict life success and promote positive behaviour.

Mixed Model of Emotional Intelligence

The mixed model approach to Emotional

Intelligence, articulated by Mayer, Caruso, and Salovey in 2000, adopts a broader socio-emotional perspective. This model encompasses not only cognitive abilities but also essential personality traits and behavioural components This model integrates emotional competencies with personality traits such as motivation, self-esteem, assertiveness, impulse control, emotional awareness, and empathy. By doing so, it creates a more holistic understanding of emotional intelligence that considers both innate abilities and acquired traits.

Theories and Models of IQ

Psychologists have developed various theories to explore the structure of intelligence. Among the most significant, we will examine five key theories:

- 1. Spearman's Two-Factor Theory
- 2. Guilford's Structure of Intellect Theory
- 3. Thurstone's Group Factor Theory
- 4. Gardner's Theory of Multiple Intelligences
- 5. Sternberg's Triarchic Theory

Spearman's Two-Factor Theory posits that intelligence comprises two components: general intelligence (g) and specific intelligence (s). Spearman suggested that g represents a broad cognitive ability that influences performance across a range of tasks and domains, while s accounts for the unique abilities required for specific tasks. For instance, an individual may excel in mathematical reasoning but struggle with verbal tasks, indicating a stronger s factor in mathematics compared to language skills. Spearman's approach laid the groundwork for future intelligence research by emphasizing the importance of both general and specific abilities in understanding human cognitive performance.

Guilford's Structure of Intellect Theory expanded the understanding of intelligence by proposing a multidimensional model. Guilford identified three dimensions of intellect: operations, contents, and products. Operations refer to the mental processes involved in problem-solving, such as evaluation

and synthesis. Contents denote the types of information or knowledge areas, including verbal, figural, and symbolic. Products represent the outcome of cognitive processes, ranging from units to systems. This framework highlights the complexity of intelligence, suggesting that it is not a singular entity but rather a constellation of diverse cognitive abilities that interact in various ways to facilitate problem-solving and creative thinking.

Thurstone's Group Factor Theory offers another perspective, emphasizing the existence of several distinct but interrelated primary mental abilities. Thurstone identified seven key factors, including verbal comprehension, numerical ability, spatial visualization, and memory. He argued that while a general factor of intelligence exists, it is more accurate to consider intelligence as a collection of specific abilities. This theory paved the way for further investigation into how these mental abilities correlate and contribute to overall cognitive performance, challenging the notion of a single, overarching intelligence measure.

Gardner's Theory of Multiple Intelligences revolutionized the understanding of intelligence by proposing that individuals possess a range of distinct intelligences, each representing different ways of processing information and problemsolving. Gardner identified at least eight intelligences, including linguistic, logicalmathematical, musical, bodily-kinesthetic, spatial, interpersonal, intrapersonal, and naturalistic. This theory emphasizes that traditional IQ tests may not adequately capture an individual's full range of abilities and that educational systems should recognize and nurture diverse talents. By highlighting the uniqueness of each intelligence, Gardner's theory encourages a more personalized approach to learning and assessment.

Sternberg's Triarchic Theory provides a comprehensive view of intelligence by breaking it down into three components: analytical,

creative, and practical intelligence. Analytical intelligence involves problem-solving and critical thinking skills, typically assessed through standardized testing. Creative intelligence refers to the ability to generate new ideas and think outside the box, while practical intelligence pertains to the skills needed to navigate everyday life and adapt to various contexts. Sternberg's model underscores the importance of considering different types of intelligence when evaluating an individual's cognitive abilities, advocating for a broader understanding of what it means to be intelligent. In conclusion, the study of intelligence has vielded a rich tapestry of theories that each contribute to a deeper understanding of cognitive abilities. From Spearman's emphasis on general intelligence to Gardner's celebration of diverse intelligences, these models highlight the complexity and multifaceted nature of human intellect. By examining these theories, we can appreciate the various ways individuals think, learn, and adapt, paving the way for more inclusive educational practices and assessments

The Balance of IQ and EQ: Keys to Success and Personal Growth

that recognize the richness of human potential.

When it comes to success, opinions vary on whether IQ or EQ holds greater significance. Proponents of EQ often assert, "A high IQ will get you through school, but a high EQ will get you through life." Conversely, some argue that IQ is a more reliable predictor of success, suggesting that EQ is sometimes overstated, even in emotionally demanding roles. Research indicates that success is not solely dependent on either IQ or EQ rather, it arises from the interplay between the two. This suggests that cultivating both emotional and intellectual skills is crucial for achieving overall success in life and work.

Improving both your IQ (Intelligence Quotient) and EQ (Emotional Quotient) involves a blend of strategies that enhance cognitive abilities and emotional intelligence. To boost your IQ, engage

in brain training activities such as solving puzzles, playing strategy games like chess, and using brain training apps. Regular reading across various genres helps to improve critical thinking skills. Additionally, learning new skills whether through hobbies like playing an instrument or taking online courses can stimulate your mind. Practicing problem-solving through cross words or Sudoku, and maintaining a healthy diet rich in brain-boosting foods are also effective ways to enhance cognitive function.

On the other hand, to improve your EQ, start by developing self-awareness through personality assessments to understand your emotional responses better. Practice empathy by engaging in active listening and trying to see things from others' perspectives. Enhancing social skills

through group activities or community service can help you interact better with others. Managing stress and emotions through mindfulness and meditation is essential for emotional regulation, while setting personal and professional goals allows for emotional commitment and growth. Seeking feedback from trusted individuals can provide insights into your emotional interactions and areas for improvement.

Incorporating mindfulness practices can simultaneously boost both cognitive function and emotional awareness. By implementing these strategies consistently, anyone can enhance cognitive abilities and emotional intelligence both, leading to better personal and professional relationships.





Note

Instructions for the guidance for contribution to the Indian Railway Technical Bulletin published by RDSO

Articles are invited from the serving and retired Railway personnel of the Zonal Railways, Railway Institutes and Production Units for publication in Indian Railway Technical Bulletin (IRTB) on:

- (i) Technical articles relevant to railway working.
- (ii) Reference to Railway-relevant good articles from reputed magazines.
- (iii) Short notes on handy gadgets or practical hints on care, maintenance and operation of equipment used in railway working.

About the article:

- Article should normally not exceed 3000 words. Article should begin with a synopsis, both in English & Hindi not exceeding 100 words. Reference should be quoted numerically in a bibliography at the end. Standard or well recognized notations should be used. Personal reference and lengthy quotations should be avoided.
 - In case of reference to articles (item ii above), whereabouts of the article (name of magazine, publication month, article's name, author's name), and 2-3 lines about what the article is about and how it is so good should be sent.
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