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TULTECH

A Sustainable Evolution of Indian Railway

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Abstract

This paper explores the transformative journey of Indian Railways (IR) since 1853, emphasizing restructuring, digitalization, and safety measures. IR's commitment to sustainability is evident in initiatives like e-ticketing, radio frequency-based identification (RFID)-based maintenance, safety, and disaster management. Innovations like level crossing automation and real-time information systems contribute to a safer railway ecosystem. IR's dedication to reducing greenhouse gas emissions aligns with global environmental objectives, utilizing solar and wind energy initiatives. Challenges in balancing financial performance persist and have been addressed by national government policies. As IR strives for a sustainable future, collective efforts from stakeholders, including employees and passengers, are pivotal. The vision is a modern, efficient, and environmentally conscious railway system.

Keywords: Indian Railways, Sustainability, Infrastructure Development, Disruptive Changes, Operational Efficiency, Green Energy

INTRODUCTION

Transport infrastructure is the backbone of a nation's economy and has become one of the most critical elements of economic liberalization all over the world. The Indian Railways (IR) organization structure depicts the superior-subordinate relation relationship under a single management and is unparalleled in size, scale, and operations, maintaining the needs of commuters from the time of its inception. The transformation of Indian Railways can be made possible in three ways: restructuring of the railway board, physical overhaul of processes, people, and service management standards, and digital transformation to improve customer experience and operational efficiency [1]. In 2019, Indian Railways operated 289,185 freight wagons, 74,003 passenger coaches, and 12,147 locomotives [2]. The diverse fleet includes Integral Coach Factory (ICF), Rail Coach Factory (RCF), and Linke Hofmann Busch (LHB) coaches [3–5]. The expansive railway network is efficiently managed through subdivision into seven major operating zones: Northern Railway (NR), Northeast Frontier Railway (FR), Western Railway (WR), Southern Railway (SR), South Central Railway (SCR), Eastern Railway (ER), and Central Railway (CR), as illustrated in Figure 1 [6].

The creation of a smart, environment-friendly, and user-friendly mobility system is the highest priority of transport worldwide. Rail transport is recognized as a vital part of this process. The main technologies and solutions that have accelerated digital transformation in the railway sector in recent years are the Internet of Things (IoT), cloud computing, big data analytics, automation, and robotics [7]. The Indian railway network has integrated the people of India. It is the backbone of the Indian economy. According to Vision 2030, a significant focus has been given to IR system improvement, signaling systems, infrastructure development, safety, reducing operation costs, and, moreover, reducing the carbon footprint. The research paper provides a comprehensive review of the transformation of IR in the above-mentioned area. The transformation of Indian railways since inception is shown in Table 1.

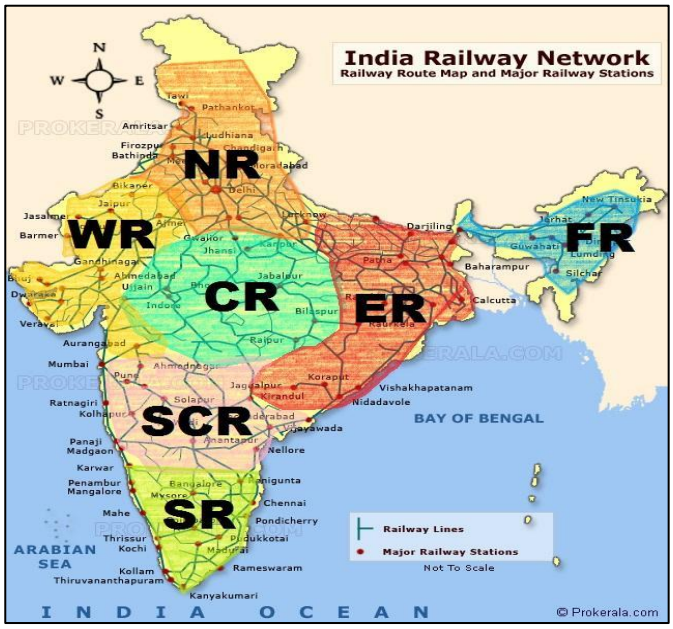

Figure 1: Major operational zones of IR [6]

Table 1: Transformation of Indian Railway

Years	Transformation of IR
1853-1869	Launching passenger rail services
1869-1900	East India Company and construction of railway lines
1901-1925	Electrification and the railway network stretched to a length of 66,000 km
1947-1980	The departure of Britain formed two nations: the railway development projects of Bengal Assam and North Western Railway stopped; the Zonal Railway was created; and there was a new drive towards electrification, adopting 25KV AC traction.
1980-2000	phasing out steam locomotives and the introduction of new technology. In 1984, the first underground railway in Calcutta was the "Computerized Passenger Reservation System."
2000-2017	Moving online, in 2002 IRCTC launched "Online Train Reservations and Ticketing." Metro Railway expanded to other major cities: Delhi (2002), Bangalore (2011), Gurgaon (2013), and Mumbai (2014).
2018 & onward	The future of Indian Railways Free Wi-Fi services would be provided at more than 7,000 stations, and by 2025, 25% of its power demand would be supplied with renewable, primarily solar

The structure of the Railway Board will be dispensed off, and a new one will be brought in. Eight Group A service of the railways will be merged into one "Indian Railway Management Service." There will be four board members (Infrastructure, Operations & Business Development, Rolling Stock, and Finance) instead of eight. The chairman will now be called the Chief Executive Officer (CEO).

Disruptive changes in Indian Railway

Disruptive change is a partial change in the portion of any industry inevitable for changes in market trends, meeting customer demand, and the benefits of the industry as a whole. Therefore, disruption has become a routine reality of every business, and it does not matter to the business. In the present scenario, many established business organizations, including Indian Railways, are facing an existential threat.

The rapid development of machines' abilities, mechanization of intelligence, and computational techniques transform the total business structure. Computing algorithms are being taught to obtain data from other machines, make logical associations between pieces of data, and make optimal decisions based on the patterns of decision-making. Disruptive change usually affects many business organizations, and the effects that they leave behind depend on the preparedness of the concerned portion of the organization dealing with it and the way it will handle it generally. Whatever the result, changes are inevitable, and only the strongest will win and survive.

Disruptive change is a continuous improvement process. For the success of a business organization, the management should identify disruptive change indicators as early as possible. Knowing the past and considering present trends, the future possibilities should be ascertained. Since its inception, Indian Railway has adopted many disruptive changes to match the technological development of developing countries, which have been discussed below.

e-Ticket & Freight information system

The Indian Railway Catering and Tourism Corporation (IRCTC) has revolutionized the life of the common man. Starting in August 2002, the company booked only 27 tickets on the first day of internet ticketing, and as per the record of its 15.88 lakh e-tickets booked on March 21, 2022, At the same time, there is a revolutionary change in the processing of ticket checks for onboard passengers.

Real-time information on freight that provides a clear picture of freight transportation and movements allows commuters to get information about capacity and freight management so that necessary planning for booking rolling stock may be done with ease. It also provides the real-time location of their booked freight and goods positions so that the next decision for departure from the station will be made.

Preventive Maintenance by Radio Frequency Identification Devices (RFID)

Indian Railways is providing radio-frequency identification (RFID) tags mounted on its wagons, coaches, and tracks to improve the safety and reliability of the rolling stock, as depicted in Figure 2. The tags are used with all types of rolling stock as well as major assemblies, and the base metal of the tag can be steel, stainless steel, or aluminum as per IR standards. Railroads will have an easier time determining the precise location of wagons, locomotives, and coaches, in addition to the whereabouts of their fuel, by utilizing RFID tags. Such information is being maintained manually, which raises concerns regarding its accuracy.

Therefore, an increasing transition is occurring from routine maintenance to anticipatory maintenance of rolling stock through the utilization of IT. It is anticipated that shortages of wagons, locomotives, and coaches will become more transparent with the implementation of RFID. In order to increase the safety of rail passengers, especially women, CCTV cameras will be installed in coaches designated for ladies.

Figure 2. RFID Tag used in IR

Crossing Level, Interlocking & Dispatching

A crossing level is a place where the road and the railway tracks are not separated by using a bridge or a tunnel and is one of the most important accident-prone areas. Each level crossing has unique and typical characteristics. These high-risk intersection spots [8] of transport systems in general and railways, in particular, are matters of concern all over the world. There must be a warning signal with an alarm for the vehicles to stop so that the trains may run without any disturbance. Usually, there are signs indicating the crossing. In particular for the Indian Railways, an intelligent, dynamic, integrated system of safety nets is developed using contemporary technology and the behavioral psychology of road users. A microcontroller (AT Mega 328P), cameras, digital sensors, a buzzer, signal lights, flippers, a comparator, and a position encoder are all integrated into the crossing level. The system is fully automated and impregnable. Once more, interlocking is engineered to permit train movement at crossings and junctions unless it is confirmed that the route is secure, as seen in Figure 3.

Figure 3. Modern Technology for Level Crossing [9]

Electronic interlocking (EI) is being adopted on a large scale in train operation and safety. Increased line capacity for high-density routes and automatic block signalling are being provided. An indigenously developed automatic train protection system called KAVACH has been deployed to locomotives for the National Train Protection System.

Infrastructure Development

Indian Railways is currently suffering from a serious underinvestment in infrastructure, which imposes a heavy burden on the country. This is measured in terms of operating ratio (OR). OR is calculated based on the amount of money the railways spend to earn a hundred rupees. It also depends on the cost per route (Km) of freight and passenger traffic. However,

IR has taken the initiative for the Public-Private Partnership (PPP) model and decentralization of authority to improve the financial condition towards infrastructure development with a vision towards reform, perform, and transform. The following are a few points where stress has been given:

- Technical Upgradation of Locomotives: Manufacture of new generation, high-horsepower, energy-efficient IGBT-based three-phase locomotives (WAP-5 and WAP-7), capable of hauling trains at speeds of 140 kmph and 160 kmph, respectively, for traffic and high-horsepower (12000 hp) freight locomotives.
- High-Speed Rail (Bullet Train): Introduction of Rajdhani, Shatabdi, Duranto, and presently Bande Bharat Express with a speed of 160 kmph.
- Intermodal Transport: Developing efficient connections between rail, road, and ports to create a seamless intermodal transportation system.
- Skills and Training: Establishing training institutes for skill development in railway-related fields with a fully functional Railway University.
- Augmentation and upgradation of track capability of carrying heavier freight trains at 25-tonne axle load and achieving higher speeds of 75/100 Kmph for good trains and speeds of 160/200 Kmph. mail / express ensuring reliable safety standards for the tracks and modernization of maintenance practices.
- The setting up of real-time information systems (RTIS) to provide real-time information at stations and on running trains was developed in collaboration with ISRO [10].
- Provision of internet access at 342 railway stations (58 'A1' class and 284 'A' class) and establishment of a unified Internet Protocol (IP)-based ICT platform for 6000 railway stations

Safety and Disaster Management

The accident problem in railway transportation is of significant severity, mostly attributable to the intricate flow pattern exhibited by high-speed, low-speed, express, and cargo trains. Significant losses of life and property are in addition to disruptions in the rail transportation system that result from railway accidents. Consequently, railway engineers bear the enormous burden of assuring the safety and security of rail passengers and facilitating their travel. Although complete eradication of railway accidents is unattainable, the accident rate can be substantially diminished via the application of appropriate engineering and management strategies. A rigorous investigation and evaluation of railway accidents are therefore necessary. A thorough examination of the accident's root cause will facilitate the development of preventative measures pertaining to infrastructure, design, control, and human error [11]. Safety is one of the most vital issues in any transport system. It is the responsibility of the Operating Department of IR to ensure that trains reach their destination safely. For safety, the following measures are to be taken:

- Implementation of the latest track machines for mechanized maintenance work.
- Installation of wheel impact load detectors.
- Upgradation and modernization of coaching depots, workshops, and production units for proper maintenance of periodical overhauling of coaches, wagons, bogies, parts, and equipment.
- Modernization of disaster management systems, information and communication systems, and services at the time of accidents for saving property and lives of innocent passengers

In the last 12 years (2006–18), Indian Railway (IR) faced a huge economic loss of Rs. 65048 crore due to accidents with an average of Rs. 5420 crore, along with the disruption of the railway's system and the number of passengers killed and injured. This huge amount could be utilized for the development of railways as well as for the country. At the time of the train accident ('The Golden Hour'), there was an urgent need for rescue and relief services for passengers. 174 Accident Relief Medical Equipment (ARME) Vans and 185 Accident Relief Trains (ARTs), including several Self-Propelled Accident Relief Trains (SPART), contain medicines, resuscitation equipment, dressings, disposables, etc. for use in emergency and operation theaters for conducting major surgery. have been working throughout the Indian Railways. Doctors, paramedical staff, rescue workers, and engineers are ready to offer their services with top priority and rush to the accident spot as early as possible.

Reduction of Green House Gas Emission

IR is committed to transforming itself into an eco-friendly mode of transportation by reducing its carbon footprint. This commitment was made during the Glasgow Climate Summit, with a target to achieve this transition by 2030. As per the United Nations Climate Change, the Indian railway sector contributes significantly, accounting for 12 percent of the country's greenhouse gas emissions. In the fiscal year 2021-2022, Indian Railways successfully transported over 1400 metric tons of freight, marking a 15% increase compared to the previous year, and it has ambitious plans to transport 8.6 billion passengers in 2022–23. To align with its green mission, Indian Railways has embarked on a journey of adopting numerous measures aimed at diminishing its carbon footprint and eventually becoming a net-zero carbon emitter by 2030. Key steps taken by IR in its Green Energy Transition include:

- **Utilization of Vacant Land for Solar Energy:** IR has begun harnessing the potential of its vacant land parcels by setting up land-based solar plants. Notably, the Bina Solar Power Project, launched in February 2023, is a pioneering initiative that generates and directly supplies solar electricity at 25 kV overhead electrical equipment to power trains. Additionally, Indian Railways is investing in wind energy, with wind turbines installed along railway tracks.
- **Rooftop Solar Photovoltaic (SPV) on Railway Coaches** – Inspired by countries like Italy, France [12], and the United States, India introduced the installation of solar photovoltaic panels on the rooftops of railway coaches [13]. This initiative began in 2011 on the Pathankot (Punjab) line and expanded to the Kalka–Shimla line in 2019 [14]. A study conducted in 2015 revealed that these SPV systems could provide approximately 74 percent of the power requirements for rail coaches during the summer and 25 percent during the winter.

CHALLENGES FOR SUSTAINABLE GROWTH AND WAY FORWARD

The pursuit of sustainable expansion for Indian Railways (IR) is not without its share of obstacles, which require careful consideration. Particularly noteworthy is the striking disparity between the lucrative freight section and the loss-making passenger segment, which indicates that financial performance emerges as a major worry. Despite the solid 7 percent expansion of the Indian economy, the yearly growth rates for freight volume and revenue were only 1 percent and 3 percent, respectively, between April and July 2023. Complicatedity is introduced by the escalating rivalry from road travel, which is expanding at a quicker rate than rail transport. IR is faced with an additional hurdle in maintaining and increasing its market share in freight transportation due to the volatile Net Tonne Kilometres (NTKM), which requires a thorough restructuring of railway transportation. Modernization of critical

infrastructure is required immediately; this includes the implementation of high-speed rail, reconstruction of stations, doubling of track lengths, refurbishment of coaches, GPS tracking, and digitalization to improve safety, efficiency, and save costs. In order to facilitate sustainable growth, the Indian government has implemented critical policies such as the National Logistics Policy (NLP), which emphasizes the establishment of a national logistics portal and interdepartmental integration, and the PM GatiShakti (PMGS) policy, which aims to establish a seamless multi-modal transport network. In order to achieve successful road and port-led growth, initiatives such as 'Sagarmala' and 'Bharatmala' must be seamlessly connected with the Indian Railways. The utilization of "Dedicated Freight Corridors" is essential for enhancing freight transit. In addition to infrastructure development, the upgrading of the Indian railways represents national pride and desire. The goal is to construct a railway network that is environmentally sustainable and capable of contributing to socioeconomic growth and serving the needs of the present and future. The achievement of this objective requires the collaboration and dedication of every stakeholder, with a special emphasis on the railway staff and patrons, who serve as the pillars and lifeblood of the Indian Railways.

CONCLUSIONS

In conclusion, the transformation of Indian Railways (IR) stands at the intersection of technological innovation, operational efficiency, and sustainable growth. The monumental journey from its inception in 1853 to the present day showcases an evolution shaped by disruptive changes and visionary initiatives. The restructuring of the Railway Board, physical overhaul, and digital transformation underscore IR's commitment to efficiency and customer-centric operations. The disruptive changes in IR have not only improved operational efficiency but have also enhanced passenger experience and safety. The introduction of e-ticketing and freight information systems through IRCTC has revolutionized ticketing processes and provided real-time insights into freight movements. The implementation of radio frequency identification devices (RFID) ensures the safety and reliability of rolling stock, paving the way for predictive maintenance.

Infrastructure development remains a cornerstone for the sustainable growth of Indian railways. From high-speed rail projects to intermodal transport connectivity, the focus on upgrading tracks, stations, and technological capabilities is evident. The integration of the Public-Private Partnership (PPP) model and decentralization of authority demonstrate a strategic approach to overcome financial challenges and foster infrastructural development. Safety and disaster management have been prioritized to mitigate accidents and enhance passenger security. Initiatives like level crossing automation, electronic interlocking, and real-time information systems contribute to a safer and more secure railway ecosystem. Moreover, IR's commitment to reducing greenhouse gas emissions aligns with global environmental goals, utilizing solar and wind energy initiatives to create a more sustainable and eco-friendly mode of transportation. However, challenges persist, particularly in balancing the financial performance between the profitable freight segment and the loss-making passenger segment. The competition from road transport and the need for comprehensive infrastructure modernization demand strategic solutions. The Government of India's policies, such as PM GatiShakti and the National Logistics Policy, provide a roadmap for seamless integration and development. As IR charts its course towards a sustainable future, it calls for collective efforts from all stakeholders. Railway employees and passengers, integral to the functioning of Indian Railways, play a crucial role in realizing the vision of a modern, efficient, and environmentally conscious railway system. The journey towards

sustainable growth is ongoing, and with concerted efforts, Indian Railways aims to be a beacon of excellence in the global transportation landscape.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interests associated with this publication.

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