Comparative Efficiency Analysis of Rail Freight Divisions in Indian Railways

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DECLARATION

I, DHARINEESH K M, bearing Register Number: 2303305013, student of MBA International Transportation and Logistics Management, at School of Maritime Management, Indian Maritime University, Chennai Campus, hereby declare that the project report titled "Comparative Efficiency Analysis of Rail Freight Divisions in Indian Railways" is my original work. This report is being submitted in partial fulfilment of the requirement for the award of the degree of Master of Business Administration (MBA) In International Transportation and Logistics Management (ITLM). The project report is the output of my learnings and observations of my research under the guidance of Dr. M Sekar, Assistant Professor School of Maritime Management, Indian Maritime University, Chennai Campus. I declare that the information submitted is true and original to the best of my knowledge.

K.M [signature]

Signature

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CERTIFICATE

This is to certify that this project reported "COMPARATIVE EFFICIENCY ANALYSIS OF RAIL FREIGHT DIVISIONS IN INDIAN RAILWAYS is submitted in partial fulfilment for requirement of awarding the degree.

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ABSTRACT

This analysis determines the efficiency of Indian Railways' freight divisions in operation based on the Data Envelopment Analysis (DEA) approach, a non-parametric method that allows relative efficiency assessment of decision-making units. As the Indian Railways is among the biggest freight carriers in the world, analysis of its divisions' efficiency is important in order to boost productivity, optimize the use of resources, and inform the investment of infrastructure.

An output-oriented DEA model with Variable Returns to Scale (VRS) assumptions is utilized in the analysis to evaluate performance over several divisions in a span of ten years (2013–2024). The input variable was Net Tonne Kilometres (NTKM), whereas freight volume (million tonnes) and freight revenue (crores) were utilized as output measures. Division-level data was fetched from authentic Indian Railways statistical reports and pre-processed to ensure uniformity. The DEA model was applied with R programming, which also facilitated strong data visualization in terms of boxplots and heatmaps to understand spatial and temporal efficiency trends.

The outcomes indicate large differences in efficiency between zones and over years. Some divisions, especially those in the South Eastern and Eastern zones, consistently perform at or close to the efficiency frontier, while others in central and northeast regions show lower and less stable efficiency scores. Benchmarking analysis identified high-performing divisions that could provide a reference unit to benchmark against for poorly performing areas, where the output targets are measured for improvement.

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INTRODUCTION

1.1 INTRODUCTION TO RAIL TRANSPORT

Railway transport represents one of the most enduring and significant modes of transportation, playing a key role in the transportation of goods and people within a country. As a land transport mode, railways offer an energy-efficient, environmentally friendly, and capacity-rich alternative to road and air transport, thus placing themselves as an integral part of economic development, regional growth, and cross-country integration.

Worldwide, rail transport has played a significant role in industrial growth and globalization by facilitating the movement of bulk materials, farm produce and finished products. Specifically, railway freight movement is the lifeline for transport in industries such as mining, energy, manufacturing and agriculture. It is preferred because it can carry bulky amounts of products over longer distances at reduced costs relative to other modes of land transport.

Indian Railways (IR) is the backbone element of the Indian transport infrastructure, which allows passengers and cargo to be moved within the country. Governed by the Government of India through the Ministry of Railways, Indian Railways is one of the largest and most complex railway systems globally, covering over 67,000 kilometers of track and over 7,300 stations.

Every day, Indian Railways operates about 13,000 passenger trains and 8,000 freight trains, carrying around 23 million passengers and over 3 million tonnes of cargo. The freight business is particularly critical in ensuring the financial viability of the railway network, with revenue from it contributing over two-thirds of its total income.

The major commodities carried include coal, iron ore, cement, petroleum products, food grains, fertilizers, and containerized freight. Coal remains the dominant freight commodity, accounting for a high percentage of volume and revenue. The ability to move large volumes of merchandise over long distances in a cost-effective, energy-efficient, and environmentally friendly manner underscores the key position of rail freight in India's industrial and economic development.

Over the last few years, Indian Railways has introduced a series of modernization programs with the objective of improving its freight handling capacity and operational efficiency. Major initiatives include:

- The creation of Dedicated Freight Corridors (DFCs) to decongest existing tracks and enable faster movement of goods,
- The large-scale electrification of tracks to reduce dependence on fuel,
- The implementation of digital systems, such as the Freight Operations Information System (FOIS),
- Fostering of Public-Private Partnerships (PPP) towards setting up freight terminals and logistics hubs.

Despite these developments, Indian Railways face several issues, including the mounting competition of road transport, the need for infrastructural upgrading, and residual operating inefficiencies. The changing nature of the logistics industry demands continued improvement in the quality of service, reliability, and operational effectiveness.

1.1.1 DIVISIONS OF INDIAN RAILWAYS: STRUCTURE AND SCOPE IN FREIGHT TRANSPORTATION

Indian Railways, the lifeline of India's transport system, is organized into a hierarchical administrative structure to effectively manage its vast network. At the apex, the Ministry of Railways oversees national policy-making and strategic decisions.

Beneath it, the network is divided into zones and further subdivided into divisions, which form the basic operational units.

As of 2024, Indian Railways consists of 19 zones, which are collectively managed by 70 divisions.

Each zone is headed by a General Manager (GM), and each division is managed by a Divisional Railway Manager (DRM), who oversees all operational, commercial, safety, and maintenance activities within their respective territorial jurisdiction.

1.1.2 ROLES AND RESPONSIBILITIES OF DIVISIONS

Divisions hold a central role in executing Indian Railways' core functions, especially in freight transportation. Key responsibilities include:

- Management of train operations (freight and passenger)
- Coordination of freight movement with industries, ports, and terminals
- Revenue collection from freight operations
- Infrastructure maintenance, including tracks, wagons, and locomotives
- Monitoring and ensuring safety and punctuality
- Facilitating customer services for freight clients and industries

Divisions are empowered to take localized operational decisions while adhering to the broader strategic framework set by their respective zones and the Railway Board.

1.1.3 DIVISIONS AND FREIGHT TRANSPORT EFFICIENCY

Freight transportation is heavily dependent on the operational performance of divisions. Factors such as wagon turnaround time, train scheduling efficiency, terminal handling capacity, and infrastructure quality at the division level directly impact the volume of freight moved, the earnings generated, and overall service reliability.

- Different divisions experience variation in freight performance based on:
- Commodity profile (e.g., coal, steel, cement, foodgrains)
- Geographical advantages (access to ports, mines, industrial belts)
- Availability of dedicated freight infrastructure

Thus, analyzing the freight efficiency at the division level provides valuable insights for improving operational productivity across Indian Railways.

1.1.4 List of Indian Railways Divisions (as of 2024)

Zone	Divisions
Central Railway	Mumbai, Bhusawal, Pune, Solapur, Nagpur
Eastern Railway	Howrah, Sealdah, Asansol, Malda
East Central Railway	Danapur, Dhanbad, Mughalsarai, Samastipur, Sonpur
East Coast Railway	Khurda Road, Sambalpur, Waltair
Northern Railway	Delhi, Ambala, Firozpur, Lucknow (NR), Moradabad
North Central Railway	Allahabad (Prayagraj), Jhansi, Agra
North Eastern Railway	Izzatnagar, Lucknow (NER), Varanasi
Northeast Frontier Railway	Katihar, Alipurduar, Lumding, Tinsukia, Rangiya
North Western Railway	Jaipur, Ajmer, Bikaner, Jodhpur
Southern Railway	Chennai, Tiruchirappalli, Madurai, Palakkad, Salem, Thiruvananthapuram
South Central Railway	Secunderabad, Hyderabad, Vijayawada, Guntakal, Guntur, Nanded
South East Central Railway	Bilaspur, Raipur, Nagpur (SEC)
South Eastern Railway	Kharagpur, Chakradharpur, Adra, Ranchi

South Western Railway	Hubballi, Bengaluru, Mysuru
Western Railway	Mumbai Central, Ratlam, Ahmedabad, Rajkot, Bhavnagar, Vadodara
West Central Railway	Jabalpur, Bhopal, Kota
Metro Railway (Kolkata)	Kolkata Metro
South Coast Railway (new)	Vijayawada, Guntur, Guntakal (newly organized)
Konkan Railway Corporation	Entire coastal route (special case, operates independently)

Table 1.1 Divisions in the Indian Railways

1.2 OBJECTIVES OF THE STUDY

- To Study the relative freight operational efficiency within Indian Railways divisions.
- To Analyze the performance of division within Indian Railways.
- To Suggest Findings from the above study.

1.3 SCOPE OF THE STUDY

The present study seeks to assess the operational efficiency of the rail freight divisions of Indian Railways during the timeframe from 2013 to 2024. By employing Data Envelopment Analysis (DEA), which is a non-parametric and output-oriented methodology, this research examines the efficacy with which different divisions transform freight transportation activities into measurable results, including freight volume and revenue. Data Envelopment Analysis represents a mathematical approach grounded in production theory alongside the tenets of linear programming. This enables the assessment of how efficiently a firm, organization, agency, or comparable entity produces a particular set of outputs using the available resources compared to other players in the dataset (Ozbek et al., 2009). The study uses Net Tonne Kilometers (NTKM) as a measure of operational effort and total freight tonnage moved and freight revenue collected as key measures of output. Divisions in Indian Railways are treated separately for each year to allow for cross-sectional and longitudinal comparison of efficiency.

Key aims are:

- To identify divisions that fall on the frontier of efficiency (high performers).
- To identify divisions showing inefficiency and to estimate the magnitude of improvements possible.
- To examine trend over the years in freight efficiency in order to identify patterns of improvement or worsening.
- To supply evidence-based advice on operational improvement and policy interventions.

The limits of this study are within the available division-level freight operations data available through Indian Railways' official reports. Passenger services, infrastructure investment, and other ancillary services are beyond the direct scope of this study. Nevertheless, the study offers important observations into the freight segment's contribution towards increasing the financial and operational efficiency of Indian Railways.

1.4 RESEARCH DESIGN

This study employs a quantitative, non-parametric analytical method to evaluate the operational effectiveness of freight transport in Indian Railways' divisions. The methodology is centered on Data Envelopment Analysis (DEA), specifically an output-oriented model with Variable Returns to Scale (VRS), to analyze the relative performance of divisions for the period 2013–2024.

Data Envelopment Analysis (DEA) is chosen for its ability to handle multiple inputs and outputs without requiring a known functional form, making it especially well-suited for measuring efficiency in complex, resource-intensive systems like railway freight operations.

1.4.1 DATA SOURCES

Secondary data obtained from:

- Annual Statistical Statements of Indian Railways
- Freight Operations Information System (FOIS) reports
- Official publications such as the "Indian Railways Yearbook" over various years.

The data set includes freight tonnage, net tonne kilometers (NTKM), and freight revenue, covering all major operational divisions in Indian Railways.

To the extent required, adjustments for units (e.g., conversion of tonnes to million tonnes) and normalization of data were carried out to maintain consistency across divisions and time periods.

1.4.2 CHOICE OF DECISION MAKING UNITS (DMUS)

Every division-year pair is treated as an independent Decision Making Unit (DMU) to enable both cross-sectional (across divisions) and longitudinal (over time) analyses of efficiency.

For example:

- "Northern Railway – 2014"
- "South Eastern Railway – 2017"

- This approach enables the dynamic tracking of performance trends and temporal efficiency variations.

1.4.3 VARIABLES USED IN DEA

Type	Variables	Description
Input	Net Tonne Kilometers (NTKM)	Total freight work performed (weight × distance)
Outputs	Freight Tonnage Carried (Million Tonnes)	Total quantity of goods transported
	Freight Revenue (₹ Crores)	Earnings from freight services

Table 1.2 Variables used in DEA

An output-oriented DEA model is applied, reflecting the operational objective of Indian Railways divisions to maximize freight handling and revenue generation given available infrastructure and resources.

1.4.4 DEA MODEL SPECIFICATION

The study employs the Banker, Charnes, and Cooper (BCC) Model (1984), which allows for Variable Returns to Scale (VRS), acknowledging that divisions may operate under different operational scales and resource conditions.

Model characteristics:

- Orientation: Output-oriented
- Returns to Scale: Variable (VRS)
- Mathematical Tool: Data Envelopment Analysis
- The VRS assumption is particularly important as divisions differ in geographic size, cargo profile, and operational capacities.

1.4.5 DATA ANALYSIS AND TOOLS

- Data processing, DEA modeling, and efficiency score generation were performed using:
- R Software, utilizing the Benchmarking package
- Microsoft Excel for initial data cleaning and transformation
- Visualization Tools (e.g., ggplot2 in R) to generate efficiency trend graphs and division comparisons
- DEA scores (efficiency scores) were computed for each DMU. Scores of 1.0 indicate efficient units operating on the production frontier, while scores below 1.0 indicate relative inefficiency.

1.4.6 ANALYTICAL FRAMEWORK

The analytical process involved:

- Data preparation and organization by division and year
- Execution of DEA to compute efficiency scores
- Identification of efficient and inefficient divisions
- Benchmarking inefficient divisions against efficient peers
- Analyzing efficiency trends over the studied period (2013–2024)

The final results provide actionable insights for refining freight management practices, optimizing resource allocation, and formulating strategic interventions to enhance Indian Railways' freight efficiency.

1.5 LIMITATIONS OF THE STUDY

While this study provides important insights into the operational efficiency of Indian Railways freight divisions using Data Envelopment Analysis (DEA), certain limitations must be acknowledged:

1.5.1 DATA AVAILABILITY CONSTRAINTS

The study relies on secondary data obtained from Indian Railways' official reports and statistical summaries.

Division-wise detailed operational parameters such as exact wagon availability, staff strength, energy consumption, and capital investments were either unavailable or inconsistent across the study period. As a result, the analysis is limited to key operational variables like Net Tonne Kilometers (NTKM), freight volume, and freight revenue.

1.5.2 EXCLUSION OF QUALITATIVE FACTORS

DEA models primarily focus on quantifiable inputs and outputs.

Qualitative aspects such as service quality, customer satisfaction, technological innovation, managerial efficiency, and infrastructural quality, which can also significantly affect operational performance, are not explicitly incorporated into the model.

1.5.3 STATIC ANALYSIS APPROACH

The DEA applied in this study assumes static conditions within each year and does not account for dynamic changes in operational environments, infrastructure upgrades, or policy reforms within a year.

A dynamic or Malmquist productivity index could provide deeper insights into year-on-year efficiency changes but was beyond the scope of this study.

1.5.4 HOMOGENEITY ASSUMPTION

DEA assumes that all Decision-Making Units (DMUs) — here, the railway divisions — operate under similar environmental and market conditions.

However, in reality, divisions differ in geographic spread, commodity profiles, industrial linkages, and traffic density, which may influence their operational results independently of their managerial efficiency.

1.5.5 POTENTIAL MEASUREMENT ERRORS

Errors in data reporting, compilation discrepancies, or rounding-off practices in official railway statistics could affect the accuracy of input and output measurements, thus influencing the calculated efficiency scores.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

2.1 LITERATURE REVIEW

Measurement of the efficiency of railway operations has increasingly been important in today's transportation environment, with pressure from economic factors, environmental issues, and increased competition from other modes of transport. Of all the methodological tools that are available for performance measurement, DEA has proved to be an especially strong and adaptable tool for benchmarking and efficiency analysis in rail.

Indian Railways, with its status as a global giant of railway systems, offers an intriguing case study for efficiency measurement. With its hierarchical organizational system divided across multiple zones and divisions, diverse operating environments, and economic and social significance, Indian Railways is the quintessential case of the challenges and possibilities of utilizing complex performance measurement approaches to railway systems. The freight segment, especially, is a key segment of Indian Railways' operations, wherein the segment contributes significantly to revenue generation and plays a major role in the country's economic growth.

This in-depth examination investigates the intersection of three major themes: the use of DEA in railway efficiency measurement, the significance of division-level performance measurement in railway companies, and the particular scenario of freight transport in Indian Railways. Through a study of these interrelated areas, we seek to build a rich understanding of how sophisticated analysis techniques can be applied to improve operational performance, provide evidence for strategic decision-making, and foster ongoing improvement in railway freight operations.

The decade between 2013 and 2024 has seen considerable changes in the freight operations of Indian Railways, such as technological upgradation efforts, policy overhauls, organizational reorganization, and strategic reactions to external shocks like the COVID-19 pandemic. These have brought about challenges and opportunities for measuring efficiency, which requires a critical review of current methodological thinking and its fit to the new operational reality.

This study aims to conduct a review of the literature, determine methodological advances and shortcomings, discuss contextual influences on divisional performance, and outline an integrated framework for evaluating and improving the efficiency of Indian Railways' freight operations. By doing so, it hopes to advance theory on the evaluation of railway efficiency as well as serve the practical need for enhanced operational effectiveness in one of the planet's most evolved and important railway systems.

2.1.1 DATA ENVELOPMENT ANALYSIS: THEORETICAL FRAMEWORK

2.1.1.1 Mathematical Foundations of DEA

A non-parametric sequentially linear frontier that encompasses all of the observed Decision-Making Units (DMUs) is constructed using linear programming techniques in Data Envelopment Analysis, a frontier-oriented approach to efficiency evaluation. Since its inception by Charnes, Cooper, and Rhodes in 1978, DEA has developed into a sophisticated methodological tool with numerous extensions and modifications appropriate for a range of analytical contexts.

Building a frontier for generating possibilities from observed input-output pairs serves as the foundation for DEA, and efficiency is determined by the relative distance of each DMU from this frontier. DEA is highly effective in complex operational settings such as railway systems because it does not require a priori functional form specification of the production frontier, unlike parametric methods like Stochastic Frontier Analysis (SFA) where it can be challenging to specify the underlying production technology.

The mathematical formulation of the basic DEA model begins with the concept of technical efficiency as the ratio of weighted outputs to weighted inputs:

Efficiency = Weighted sum of outputs / Weighted sum of inputs

For a set of n DMUs, each utilizing m inputs to produce s outputs, the efficiency of DMU_0 can be expressed as:

$$\max h_0 = \Sigma_r u_r y_{r0} / \Sigma_i v_i x_{i0}$$

subject to:

$$\Sigma_r u_r y_{rj} / \Sigma_i v_i x_{ij} \leq 1, j = 1, 2, ..., n$$

$$u_r, v_i \geq 0$$

Where:

- y_{rj} represents the amount of output r produced by DMU j

- x_{ij} represents the amount of input i utilized by DMU j

- u_r and v_i are the weights assigned to output r and input i respectively

This fractional programming problem can be transformed into a linear programming problem through appropriate mathematical transformations, facilitating practical computation and analysis.

2.1.1.2 INPUT AND OUTPUT ORIENTATIONS

DEA models may be defined in input or output orientations depending on differing views on improving efficiency:

1. Input-Oriented Models: These attempt to minimize inputs while producing the same output quantity. The efficiency question posed is: "By how much can input quantities be proportionally reduced without changing the output quantities produced?" This orientation makes most sense in situations where decision-makers have more control over input usage than over output production, as is frequently the case in railway operations where capital and labor inputs are relatively invariant in the short run.".

2. Output-Oriented Models: These are concerned with maximizing outputs with given inputs. The efficiency question asked here is: "By how much can output quantities be proportionally increased without changing the input quantities involved?" This

orientation could be more suitable in scenarios where there is a requirement to maximize the provision of service with existing resources.

The input or output orientation should be based on the realities of operation and managerial priorities in the railway system that is being studied. An input orientation may be more suitable when cost minimization and resource maximization are priorities in freight operations, while an output orientation will be more appropriate when priorities are to increase freight capacity and service coverage.

2.1.1.3 RETURNS TO SCALE CONSIDERATIONS

Returns to scale (RTS) concerns are at the forefront of DEA applications to railway networks, especially considering the capital-intensive nature of the railway business and scale economies potential. Varying DEA models have different assumptions regarding returns to scale:

1. Constant Returns to Scale (CRS): The CCR model envisions CRS, which means a proportional expansion of all inputs results in the same proportionate expansion of outputs irrespective of the scale of operation. Such an assumption might be valid for comparing optimal scale-operating DMUs but can penalize sub-optimal scale-operating DMUs by virtue of several constraints.

2. Variable Returns to Scale (VRS): The BCC model is based on the assumption of VRS, where increasing, decreasing, or constant returns to scale can occur at varying

levels of operating scales. This assumption acknowledges that all DMUs are not optimally scaled and is a more flexible approach for efficiency measurement.

3. Non-Increasing Returns to Scale (NIRS): This is a middle-level assumption admitting constant and diminishing returns to scale but ruling out increasing returns to scale. It can be done by altering the convexity constraint to $\Sigma_j \lambda_j \leq 1$.

4. Non-Decreasing Returns to Scale (NDRS): On the contrary, this assumption admits constant and increasing returns to scale but rules out diminishing returns to scale, implemented by the constraint $\Sigma_j \lambda_j \geq 1$.

The scale efficiency of a DMU may be evaluated by comparing the efficiency scores of the DMU under CRS and VRS assumptions. In case the efficiency scores are different, the DMU is scale inefficient, reflecting that the DMU is not in its optimal scale. The type of scale inefficiency (whether due to increasing or decreasing returns to scale) can be established by comparing efficiency scores under VRS and NIRS assumptions.

In freight rail operations, scale efficiency analysis can be useful in yielding insights into optimal operating scale for various categories of freight services to guide strategic capacity expansion, service consolidation, or resource reassignment decisions.

2.1.2 EVOLUTION OF DEA APPLICATIONS IN TRANSPORTATION

2.1.2.1 HISTORICAL DEVELOPMENT

The use of efficiency analysis techniques in the transportation field has undergone fundamental changes in the last few decades, reflecting both improved methods and shifting policy agendas. Early performance measurement practices in transportation drew largely on partial productivity measures, e.g., labor productivity or capital productivity, and they yielded useful but limited views of operating efficiency.

The arrival of frontier analysis methods in the 1970s was a major methodological advance that allowed greater thoroughness in measuring technical efficiency along multiple input and output dimensions. Charnes, Cooper, and Rhodes' 1978 creation of Data Envelopment Analysis provided an enormously influential non-parametric tool for efficiency measurement that soon found wide acceptance in transportation research.

The 1980s and the early 1990s saw the first uses of DEA in different transportation settings, such as airports, seaports, and city public transit systems. These initial uses generally involved simple efficiency comparison with conventional DEA models, without much regard for methodological enhancements or contextual considerations.

The late 1990s and early 2000s witnessed an increased use of DEA in railway systems, with waves of railway restructuring and reforms in most nations. These analyses investigated efficiency implications of different organizational forms, ownership structures, and regulation regimes, informing policy issues surrounding railway liberalization and privatization.

The decade from 2000 to 2010 saw increasing methodological refinement in DEA use in transportation, with the development of sophisticated techniques like network DEA, two-stage DEA, and bootstrapped DEA. These advances in methodology provided more subtle examination of complicated transportation activities as well as more robust statistical inference.

Since 2010, DEA applications in transportation have increasingly incorporated sustainability considerations, reflecting growing concern about environmental impacts of transportation activities. This trend has been particularly evident in railway studies, where environmental efficiency has become an important dimension of performance assessment alongside traditional operational and financial metrics.

2.1.2.2 KEY MILESTONES IN RAILWAY APPLICATIONS

The use of DEA in railway efficiency measurement has developed through a number of significant milestones:

1. Early Applications (1990s): Early DEA applications in railways were concerned mostly with inter-country comparisons, utilizing cross-country data to benchmark efficiency levels among nations. These tended to use rudimentary DEA models with minimal input-output specifications, yielding early indications of cross-country patterns of efficiency.

2. Post-Reform Evaluations (Early 2000s): In the aftermath of railway reforms across numerous nations, DEA studies began placing greater emphasis on assessing the efficiency consequences of varying reform frameworks. These analyses questioned whether vertically separated railways (with infrastructure and operations under distinct management) operated differently compared to vertically integrated ones, informing policy discourses regarding the most desirable industry structure.

3. Network Issues (Mid-2000s): The realization of railways as network industries instigated increased interest in modeling network features into efficiency measures. Research started to include network variables like line density, points of connection, and network structure within DEA frameworks, offering more context-specific efficiency measures.

4. Integration of Service Quality (Late 2000s): As the fear of sacrificing efficiency to achieve service quality grew, researchers started integrating quality dimensions into DEA models. Research began to include measures like punctuality, reliability, and customer satisfaction as outputs or quality-adjusted outputs in measures of efficiency.

5. Environmental Efficiency Focus (2010s): Growing environmental awareness generated greater emphasis on environmental effects in railway efficiency research. Scholars started formulating eco-efficiency DEA models that framed emissions and energy usage as undesirable outputs, allowing environmental performance to be measured along with conventional efficiency measures.

6. Methodological Sophistication (2015 onwards): Recent years have witnessed growing methodological sophistication in railway DEA applications, including the use of bootstrapped DEA for statistical inference, network DEA for process-oriented efficiency assessment, and dynamic DEA for temporal efficiency analysis. These methodological innovations have enabled more nuanced understanding of railway efficiency dynamics.

These milestones demarcate the continuous improvement of DEA applications in railroad research, from elementary cross-sectional comparisons to advanced multi-dimensional evaluations involving operational, financial, environmental, and quality factors. These developments have greatly improved the applicability and value of DEA for assessing railroad performance and policy formulation.

2.1.3 ADVANCED DEA METHODOLOGIES IN RAILWAY STUDIES

2.1.3.1 NETWORK DEA FOR MULTI-STAGE PROCESSES

Railway operations are by nature complex chains of interdependent processes that range from infrastructure management and rolling stock maintenance to train operation and terminal handling. Classic DEA models analyze such processes as a "black box" where only the correlation between aggregate inputs and ultimate outputs is considered without accounting for the intermediate processes and outputs. Network DEA overcomes this deficiency by modeling explicitly the inner structure of operations, allowing for more detailed measurement of efficiency at various points in the production process.

The network DEA method, first developed by Färe and Grosskopf (2000), breaks down the process of production into intermediate sub-processes or stages, where outputs from a stage may become inputs for further stages. This method has a number of benefits for measuring railway efficiency:

1. Process-Specific Efficiency Measurement: Network DEA allows for each phase of railway operations to be measured for efficiency, targeting particular processes where inefficiencies are likely to exist. For freight operations, this could include distinct efficiency measurement for train assembly, line haul operation, and terminal handling.

2. Intermediate Output Evaluation: Through the explicit modeling of intermediate outputs, network DEA gains visibility into the efficiency of internal processes that could be ignored by standard DEA models. In the case of railway freight, intermediate outputs could be wagon turnaround time, locomotive utilization, or terminal throughput.

3. Structural Insights: Network DEA discloses how inefficiencies in one process spread across the operational chain and unveil structural connections between various parts of railway operations. This can guide targeted improvement programs on vital process bottlenecks.

4. Optimization of Resource Allocation: Through the determination of efficiency differentials between processes, network DEA can inform resource reallocation for maximum system performance. This is especially useful in railway operations, where resources such as locomotives, wagons, and crew are to be allocated among various operational processes.

Network DEA applications in railway research have moved from rudimentary two-stage to intricate multi-stage models reflecting the complexity of railway operations. In Indian Railways' freight business, network DEA was used to examine efficiency relationships among infrastructure management, train operation, and commercial activities and uncover intricate efficiency interdependencies and process-specific opportunity spaces for improvement.

2.1.3.2 DYNAMIC DEA FOR TEMPORAL EFFICIENCY ASSESSMENT

Railway operations develop over time, with investments and decisions to operate in one time period having the possibility of influencing efficiency results in later time periods. Conventional static DEA models give snapshot efficiency judgments at individual points in time but ignore the dynamic nature of efficiency development. Dynamic DEA remedies this by explicitly accounting for temporal relationships and intertemporal dependencies in efficiency measurement.

The dynamic DEA model, introduced by Färe and Grosskopf (1996) and further developed by other scholars, introduces "carry-over activities" or "link variables" that link consecutive periods. These variables, such as capital stock, knowledge accumulation, or organizational learning, are both outputs for one period and inputs for the following period and establish an open temporal connection in the efficiency measure.

Important dimensions of dynamic DEA that heighten its usefulness for railway efficiency measurement are:

1. Investment Impact Analysis: Dynamic DEA provides the ability to analyze the impact of investment in infrastructure, rolling stock, or technology on efficiency trajectories over time. This is particularly appropriate for railways where investments

have multi-period impacts with significant time lags between investment and realization.

2. Impacts of Technology Adoption: By observing the changes in efficiency over time, dynamic DEA can determine the impact of technology adoption and diffusion on operational performance. For Indian Railways' freight operations, this approach has been used to analyze the impact of digital technologies such as Freight Operations Information System (FOIS) and automatic signaling systems.

3. Policy Reform Analysis: Dynamic DEA provides a tool to study the effects on efficiency trends of policy reforms and organizational changes. This has been applied in the analysis of Indian Railways' efficiency implications of numerous of its policy reforms, including the development of dedicated freight corridors and public-private partnerships.

4. Learning and Adjustment: Incorporating the effects of learning in the measurement of efficiency, dynamic DEA can capture how companies adapt and learn from experience accumulation and knowledge exchange. This feature is also best suited for divisional comparison of efficiency in Indian Railways, when learning and adjustment processes can differ across divisions.

Applications of dynamic DEA in railway studies have ranged from basic window analysis approaches, where moving averages of efficiency scores are used to identify trends, to sophisticated models with dedicated carry-over variables and temporal interactions. Dynamic DEA has provided insightful information regarding efficiency paths after heavy investments, policy reforms, and technological programs for Indian Railways' freight operations.

2.1.3.3 BOOTSTRAPPED DEA FOR STATISTICAL INFERENCE

A disadvantage of the traditional DEA has been its deterministic character, precluding statistical inference on efficiency estimates. DEA efficiency scores derived from a single sample of observations are prone to sampling fluctuations and capable of yielding biased or incorrect conclusions. Bootstrapped DEA, created by Simar and Wilson (1998), eliminates this disadvantage by invoking bootstrap resampling procedures in order to determine confidence intervals for efficiency estimates and enable statistical hypothesis testing.

The bootstrapped DEA approach replicates the sampling distribution of efficiency scores by repeatedly sampling from the original data and re-computing efficiency scores for each bootstrap sample. This generates a distribution of efficiency scores for each DMU from which confidence intervals can be constructed and statistical tests can be conducted. Most significant advantages of bootstrapped DEA for measuring railway efficiency are:

1. Strong Efficiency Comparisons: With bootstrapped DEA's provision of confidence intervals for the efficiency scores, comparisons across railway divisions or systems become more robust. Such statistical strength is especially important where differences in efficiency are minor, or where sample sizes are small, as in many divisional comparisons within railway systems.

2. Hypothesis Testing: Bootstrapped DEA allows for proper hypothesis testing regarding differences in efficiency between groups of DMUs or the significance of changes in efficiency over time. In the case of Indian Railways, it has allowed for statistical testing whether differences in efficiency among geographical areas or operating environments are statistically significant or just sampling artifacts.

3. Bias Correction: The bootstrap technique can detect and correct bias in efficiency estimates, especially the bias towards overestimation present in conventional DEA methods. This bias correction provides more reliable efficiency assessments, especially in small samples often common in railway divisional comparisons.

4. Specification testing of models: Bootstrapped DEA offers a platform to test various alternative model specifications, such as varying input-output combinations or returns to scale assumptions. This ability is useful in guaranteeing robust model specification in railway efficiency analysis when the correct input, output, and technological assumption choices are not self-evident a priori.

Applications of bootstrapped DEA in railway research have ranged from simple confidence interval estimation to advanced hypothesis testing frameworks investigating determinants of efficiency and group differences. For Indian Railways' freight operations, bootstrapped DEA has increased the validity of efficiency comparisons across divisions operating in varying geographical and operating environments, offering a stronger basis for performance benchmarking and improvement programs.

2.1.3.4 FUZZY AND STOCHASTIC DEA APPROACHES

Railway operations are naturally defined by uncertainty and imprecision in inputs as well as outputs. Weather conditions, reliability of equipment, and variability of demand introduce uncertainty that conventional deterministic DEA models are unable to account for effectively. Fuzzy DEA and stochastic DEA methodologies overcome these shortcomings by explicitly accounting for uncertainty and imprecision in efficiency measurement.

Fuzzy DEA, first introduced by Sengupta (1992) and later progressed by other researchers, substitutes crisp input-output values with fuzzy numbers or membership functions to reflect the embedded imprecision or vagueness of data measurement. This is especially suitable for railway efficiency measurement when:

1. Data Quality Problems are Present: Rail data can be afflicted with measurement inaccuracies, reporting discrepancies, or definitional imprecision, especially in developing countries. Fuzzy DEA is able to cope with these data imperfections by representing inputs and outputs as fuzzy sets or ranges instead of exact values.

2. There Are Subjective Components: Certain railway performance criteria, e.g., safety perception or service quality, contain subjective evaluations, which are themselves inexact by nature. Fuzzy DEA can accommodate such subjective components using suitable fuzzy representation of qualitative ratings.

3. Seasonal Fluctuations Exist: Railway freight activity is subject to substantial seasonal fluctuations in demand levels and operating conditions. Fuzzy DEA is able to address this seasonal fluctuation by modeling inputs and outputs as fuzzy ranges for the range of fluctuation across the year.

Stochastic DEA, in contrast, incorporates statistical noise through probabilistic modeling of the production frontier or efficiency distributions. This approach recognizes that deviations from the frontier may result from both inefficiency and random factors beyond managerial control. Stochastic DEA is particularly valuable when:

1. External Influences Affect Performance: Railway performance is prone to various external influences such as weather conditions, infrastructure breakdowns, and network overload. Stochastic DEA can separate inefficiency from these random external factors, offering more precise efficiency evaluations.

2. Performance Fluctuations Are Experienced: Railway freight transportation can experience performance fluctuations because of a variety of temporal factors. Stochastic DEA can capture these fluctuations with the right probability distributions, offering more stable long-term efficiency estimations.

3. Risk Considerations Matter: Railway decision-making is many times a risk-return tradeoff, especially in freight operations where reliability and consistency are appreciated in addition to pure efficiency. Stochastic DEA allows risk considerations

to be folded into efficiency measurement, yielding information about the efficiency-risk frontier.

Applications of fuzzy and stochastic DEA in railroad research have developed from general uncertainty accommodation to advanced modelling of intricate uncertainty structures. For Indian Railways' freight business, such methods have been especially beneficial in situations with data constraints, outside disruptions, or strong seasonal fluctuation, making it possible to have stronger efficiency estimates that are adjusted for inherent uncertainty in railroad operations.

2.2 LITERATURE GAP

As much as there is wide usage of Data Envelopment Analysis (DEA) in assessing transport efficiency, areas of concern exist within the Indian Railways context, especially at the division level. The majority of the available studies, i.e., Singh and Sachdeva (2016) and Bhatia and Verma (2020), tend to be based on zone-level or corridor-specific analysis, ignoring the operational detail that divisions provide. This top-level aggregation hides appreciable intra-zonal performance differences, resource deployment patterns, and freight-handling habits.

In addition, earlier DEA research on Indian Railways largely relies on technical output measures (e.g., train kilometers, freight tonnage) and frequently exclude financial performance metrics like freight revenue. As Indian Railways is in a cost-recovery framework with freight revenue cross-subsidizing passenger services, incorporating both operational and financial outputs give a more meaningful assessment of efficiency.

Another essential gap is the absence of multi-year, longitudinal analysis. Most studies evaluate efficiency with single-year cross-sectional data, which restricts observation of trends, policy effects, or structural changes over time. This restricts the scope for examining how reforms, infrastructure improvement, or external influences affect efficiency dynamically.

Furthermore, few studies actually benchmark poor-performing divisions against best-practice peers, a key aspect of DEA that allows for focused operational improvement.

This research fills these gaps by performing a divisional-level, multi-output, multi-year DEA analysis of Indian Railways freight performance between 2013 and 2024. By combining operational and financial outputs, it presents a more realistic and actionable performance benchmarking and strategic planning framework.

2.3 LITERATURE ANALYSIS

Data Envelopment Analysis (DEA) in the transport industry has come a long way since its application in such studies, with different researches employing the methodology to analyze operational performance, resource use, and policy impacts. DEA, proposed by Charnes et al. (1978), offers a strong non-parametric method of comparing more than one Decision-Making Units (DMUs) and hence is ideal for the analysis of railway activities.

The majority of the early research in this field was on international railway networks. As an example, Oum and Yu (1994) analyzed OECD railways, and Cantos et al. (1999) analyzed European railway efficiency, both noting the importance of investment in infrastructure and regulatory policies. These works illustrated the importance of DEA in large-scale transport systems, though being largely country-comparative or network-based studies.

Conversely, Indian Railways-specific literature is still quite limited and mainly focused at the zonal level. Singh and Sachdeva (2016) evaluated Indian zones with CRS DEA models but without financial performance measures. Bhatia and Verma (2020) used DEA for freight corridors but omitted traditional divisions where most freight operations really occur.

Methodologically, there are few studies that merge operational outputs (e.g., NTKM) with financial outputs (e.g., revenue from freight), even though profitability is essential in a public utility such as Indian Railways. Most studies are cross-sectional, neglecting the performance dynamics over time.

This points to a distinct research need: the necessity for a divisional-level, longitudinal DEA that combines both operational and financial outputs. By closing this methodological and contextual gap, the current research adds not just to the theoretical literature, but also to strategic management decision-making in railway operations.

CHAPTER 3

CORPORATE PROFILE

CHAPTER 3

3.1 CORPORATE PROFILE

3.1.1 INDIAN RAILWAYS

Indian Railways (IR) over a period of over 170 years has transformed from a set of unconnected rail lines owned and run by private firms under British colonialism to one of the largest railway systems in the world in single public ownership and management. This long history has influenced its present-day organizational setup and practices in a fundamental manner.

Nationalization of the railways in 1951 integrated the railway network under the Ministry of Railways, forming the basis for the present-day organizational framework. Centralized planning and control dominated the years from the 1950s to the 1980s, with a focus on development of the network, industrial growth, and obligations of social service. The 1990s saw the start of reform efforts as a reaction to economic pressures and shifting economic environment, such as the first attempts at commercial orientation and management autonomy.

More serious reform initiatives were made in the early 2000s in the form of the creation of the Indian Railway Finance Corporation to provide financing for capital, dedicated freight corridors for the movement of freight, and entry of public-private partnerships in terminal services and non-core areas. These reforms remained ongoing in the 2010s with increasing focus on modernization through technology, operational efficiency, and customer responsiveness.

Its present organizational setup mirrors this historical development, with a mix of old-fashioned railway bureaucracy and more contemporary commercial and entrepreneurial influences. At the top, the Railway Board acts as the ultimate decision-making authority, with a chairman and members looking after various functional domains like operations, infrastructure, finance, and personnel. Policy guidance and direction come from the Ministry of Railways, and the day-to-day activities are conducted through a multi-tier administrative hierarchy.

Indian Railways, the largest railway system in the world, is the key to the support of Indian economy's logistics backbone. Spread over more than 67,000 kilometers and operating under the umbrella of the Ministry of Railways, it carries millions of passengers every day as well as a tremendous amount of freight throughout the nation. During the last few decades, freight transportation has emerged as the economic pillar of Indian Railways, accounting for over 60% of its yearly earnings.

Indian Railways' freight performance has transformed over time in reaction to economic growth, policy measures, and the pace of technological change. Historically, bulk of the freight earnings came from a handful of core commodities: food grains, fertilizers, iron ore, coal, cement, petroleum products, and steel. Of these, coal has accounted for more than 40% of overall freight loading, and hence the railway plays an integral role in the Indian energy supply chain.

Between 2010 and 2020, Indian Railways increased its freight volumes consistently from about 900 million tonnes a year to more than 1.2 billion tonnes. This has been stimulated by the growth in industrial production, increased use of rail as a mode of choice for bulk cargo, and development of Dedicated Freight Terminals. The roll out of the Freight Operations Information System (FOIS) has further enabled better monitoring and planning of freight services between zones.

While there have been such improvements, a number of issues have endured. Inefficiencies in operations, low average freight train speeds (usually less than 25 km/h), confined terminal facilities, and competition with road transport have prevented Indian Railways from realizing its full freight potential. In addition, freight tariffs have been used to cross-subsidize passenger tickets, establishing an imbalanced fare structure that undermines market competitiveness.

To counter these threats and enhance performance, Indian Railways has unveiled various reforms and modernization programs. The commissioning of Dedicated Freight Corridors (DFCs), particularly the Eastern and Western DFCs, represents a revolutionary leap in separating freight from passenger flows, hence enhancing speed, reliability, and capacity. The corridors are set to carry increased axle loads, run more lengthy trains, and provide end-to-end logistics solutions through multimodal connectivity.

Another major development has been emphasis on private sector participation. Indian Railways has permitted development of Private Freight Terminals (PFTs), sidings, and even private container trains. Dynamic pricing policies, discounts on return traffic, and commodity-specific schemes have also been brought to capture more business to the railway.

Indian Railways has adopted digitalization in recent times through initiatives such as e-RD (e-Rake Demand), electronic payment gateways, and GPS-based freight tracking. These initiatives have added to greater transparency and efficiency in freight operations.

3.1.2 ZONAL AND DIVISIONAL HIERARCHY

Indian Railways functions on a three-tier administrative organization with the Railway Board at the top, zonal railways in the middle at the regional level, and divisions at the operational level. This tiered structure reconciles central policy guidance with decentralized management of operations, making it a high-complexity organizational environment with numerous levels of decision-making authority.

The zonal organization, formed in the 1950s and grown over the following decades, splits the national network of railways into geographic zones, with each managed by a zonal headquarters headed by a General Manager. There are 18 zonal railways in Indian Railways as of 2024, including Northern, Eastern, Southern, Western, Central, and other regional zones, and specialized bodies like the Dedicated Freight Corridors Corporation of India (DFCCIL).

Every zonal railway is divided into divisions, which are the major operational units charged with the day-to-day functioning of the railways in their area of jurisdiction. The divisional system, instituted in the 1960s, established operating units of reasonable size that could effectively respond to local needs and conditions while executing centralized policies and norms. Presently, Indian Railways has about 70 divisions spread over its 18 zones.

The division is the key interface between policy and operation, converting top-down directions into working realities and negotiating with local conditions and constraints. Every division is controlled by a Divisional Railway Manager (DRM) who is responsible for day-to-day operation, maintenance, commercial, and administrative activities within the divisional jurisdiction. DRM is assisted by Additional Divisional Railway Managers (ADRMs) and departmental officers in charge of particular functional domains.

This divisional and zonal structuring gives rise to an intricate organizational environment with many reporting lines, overlapping mandates, and complex coordination needs. Although this arrangement facilitates adaptation to various regional environments, it poses difficulties for performance measurement, accountability systems, and efficiency maximization, especially in inter-divisional or inter-zonal activities such as long-haul freight transport.

3.1.3 FUNCTIONAL DEPARTMENTS AND THEIR INTEGRATION

Under the zonal and divisional organization, Indian Railways functions through functional departments specializing in various areas of railway operations and management. They are:

Operations Department

Handles train scheduling, movement control, and real-time operational decisions. It coordinates with freight customers for rake planning and controls path allocation for passenger as well as goods trains.

Commercial Department

Responsible for freight marketing, pricing, customer relations, and revenue realization. It is central to wooing and retaining bulk freight customers through the formulation of customer-friendly policies and tariff structures.

Mechanical Department

Is in charge of rolling stock (wagon and locomotive) maintenance and availability. It oversees timely overhauling, repair, and technological enhancement of rolling stock for hassle-free freight train movement.

Electrical Department

Is responsible for the power and traction supply systems necessary to operate electric locomotives, which dominate freight haulage on electrified tracks.

Engineering Department

Is accountable for maintenance and development of fixed assets like tracks, bridges, yards, and terminals. Provides the structural strength necessary for handling heavy freight.

Signal and Telecommunications (S&T)

Provides secure and reliable train movement via signaling systems, route interlocking, and communication networks essential for train control and dispatching.

Accounts and Finance

Controls budgeting, tracking of expenditures, costing, and revenue reconciliation within departments. It is linked to commercial and operations groups to assist with freight revenue planning and auditing.

Personnel (Human Resources)

Controls recruitment, training, deployment, and welfare of the staff within all technical and non-technical departments.

Departmental Integration

Their integration is made possible through a Divisional Railway Manager (DRM) at the division level and a General Manager (GM) at the zonal level. Routine operations, such as freight loading, scheduling, and rake management, necessitate ongoing coordination among Operations, Commercial, Mechanical, and Electrical departments.

For instance, the Operations Department cannot book a freight train until the Mechanical Department ascertains rake availability and the Engineering Department ensures track availability. In turn, commercial realization by the Commercial Department is contingent on timely execution by Operations and infrastructure facilitation by Engineering.

Integration is enabled through:

- Freight Operations Information System (FOIS) – A digital platform linking operations, commercial, and accounts departments.
- Regular coordination meetings at divisional, zonal, and board levels.
- Joint control offices that allow real-time interdepartmental communication during critical operations.

3.1.4 IMPORTANCE IN FREIGHT EFFICIENCY

In the freight segment, interdepartmental integration ensures:

- Efficient wagon turnaround
- Real-time train routing and monitoring
- Quick resolution of bottlenecks (e.g., equipment failures, terminal congestion)
- Accurate freight billing and customer service

Figure 3.1: Zones of the Indian Railways

CHAPTER 4

ANALYSIS AND INTERPRETATION

CHAPTER 4

4.1 DATA COLLECTION

The present study is based on secondary data collected from authentic and official sources pertaining to Indian Railways' freight operations. The data spans a period of eight years (2013–2024) and covers all major operational divisions under Indian Railways that are engaged in freight transport.

4.1.1 DATA SOURCES

- Indian Railways Annual Statistical Statements (2013–2024)
- Freight Operations Information System (FOIS) reports
- Indian Railways Year Books

Where necessary, unit conversions and formatting were performed to ensure uniformity across years and divisions. For instance, freight tonnage values reported in 'thousand tonnes' were converted into million tonnes for consistency. Net Tonne Kilometers (NTKM) values, which reflect the volume of freight carried and the distance traveled, were retained in their original units (millions).

4.1.2 SELECTION OF DECISION-MAKING UNITS (DMUS)

Each railway division for each year was treated as a Decision-Making Unit (DMU), following DEA methodology. For example, "Central Railway – 2013" and "Eastern Railway – 2014" were considered two separate DMUs. This allowed both cross-sectional and longitudinal analysis of freight efficiency over time.

4.1.3 VARIABLES SELECTED

The study used an output-oriented DEA model, suitable for a context where railway divisions aim to maximize freight transport and revenue given their operational input.

Input Variable:

Net Tonne Kilometers (NTKM): A measure of freight transport effort, representing the product of freight weight and the distance moved.

Output Variables:

- Freight Tonnage (Million Tonnes): Total weight of goods carried in a given year.
- Freight Revenue (₹ Crores): Total revenue earned from freight services.

4.1.4 DATA PREPARATION

The data collected was compiled into a structured Excel file, forming a panel dataset with the following columns:

- DMU (Division-Year)
- NTKM (Input)
- Freight Volume (Output 1)
- Freight Revenue (Output 2)

Missing or inconsistent values were cleaned or interpolated based on historical trends, and the final dataset was cross-verified with multiple annual reports to ensure reliability.

4.2 DATA ANALYSIS

The data was analyzed using Data Envelopment Analysis (DEA), a non-parametric method that estimates the relative efficiency of DMUs. The analysis was conducted using the Benchmarking package in R software, applying the following specifications:

- Orientation: Output-oriented
- Returns to Scale: Variable Returns to Scale (VRS)
- Model: Banker, Charnes and Cooper (BCC) Model

4.2.1 ANALYTICAL ENVIRONMENT AND R PACKAGES

The analytical procedures were conducted using R, an open-source statistical software that supports a broad range of data science tasks. Its extensive package ecosystem and matrix computation capabilities make it particularly well-suited for non-parametric modeling approaches such as DEA.

Key R packages included

readxl	Importing Excel files
dplyr	Data manipulation and filtering
Benchmarking	DEA modeling and efficiency computation
ggplot2:	Data visualization
pheatmap and reshape2	Heatmap creation
writexl	Exporting results to Excel

Table 4.1 Key R Packages used in the analysis

Data Preparation and Import

The data was sourced from Indian Railways' official annual statistics report and included Division, Zone, Year, Net Tonne Kilometres (NTKM), Freight Tonnage, and Revenue. The data was organized so each row represented a Division-Year combination. Missing data for the year 2019 was excluded, while 2024 was retained. The dataset was cleaned and formatted before analysis.

DEA Model Specification and Execution

An output-oriented DEA model with Variable Returns to Scale (VRS) was applied. Each Division-Year pair was treated as a Decision-Making Unit (DMU). Efficient units scored 1.00, while less efficient units scored below 1. The DEA model compared each DMU's outputs to the best performers, establishing a frontier of efficiency.

Benchmarking and Target Output Calculation

DEA generated output targets for inefficient units and identified peer divisions that served as benchmarks. Targets were calculated by adjusting current outputs by the inverse of the efficiency score. These benchmarks help guide underperforming divisions towards best-practice performance levels.

Visualization of DEA Results

Boxplots displayed the distribution of efficiency scores across zones, sorted by median efficiency. High-performing zones were identified, as well as zones with inconsistent or low performance. Heatmaps showed zone-wise performance across years, highlighting trends, gaps, and variability. 2019 was excluded due to missing data.

The analysis was done using R software, with the following the code to execute Data Envelopment Analysis,

```
install.packages(c("pdftools", "stringr", "writexl"))
library(pdftools)
library(stringr)
library(writexl)
library(readxl)

getwd()
setwd("C:/Users/dhari/Documents/Project")  # Example path


# Step 1: Install and load required package
install.packages("Benchmarking")  # Run only once
library(Benchmarking)

# Step 2: Load your data
# Example structure assumed:
dea_data <- read_xlsx("Dharineesh_Data.xlsx")
# Columns: NTKM_Million (input), Freight_Tonnes_Million, Freight_Revenue_Cr (outputs)

# Step 3: Define input and output matrices
X <- as.matrix(dea_data[, "NTKM_Million"])  # Input
Y <- as.matrix(dea_data[, c("Tonnes_Million", "Freight_Revenue_Cr")])  # Outputs

# Step 4: Run DEA - output-oriented, variable returns to scale
dea_result <- dea(X, Y, RTS = "vrs", ORIENTATION = "in")

# Step 5: Extract efficiency scores
dea_data$Efficiency_Score <- dea_result$eff

# Step 6: View results
print(dea_data)


library(writexl)
write_xlsx(dea_data, "DEA_Output_Results.xlsx")
```

Figure 4.1 R program for DEA Analysis

The below table depicts the efficiency score of the all divisions across 10 years excluding 2019.

Decision Making Units Division-Year	NTKM Million	Tonnes Million	Freight Revenue	Efficiency Score
Central-2013	44393995	135216	56873278	0.632
Central-2014	45972723	142237	61737481	0.662
Central-2015	46860842	145404	66645287	0.701
Central-2016	46418916	140540	71912829	0.764
Central-2017	41450726	127876	65243570	0.776
Central-2018	45073617	143491	71971993	0.787
Central-2020	47245020	150068	71190787	0.743
Central-2021	44754353	144205	68678920	0.757
Central-2022	59066261	183661	90635654	0.757
Central-2023	62924721	202454	101522121	0.796
Central-2024	61291498	203682	103997005	0.837

Eastern-2013	19415446	128128	29238670	0.907
Eastern-2014	20197960	135926	31812570	0.929
Eastern-2015	19716205	137456	34709710	0.972
Eastern-2016	17760221	127151	33787300	0.987
Eastern-2017	18140746	133622	36794900	1.000
Eastern-2018	21258617	138058	39757347	0.923
Eastern-2020	23462090	147163	39917979	0.928
Eastern-2021	23806857	145680	43823100	0.914
Eastern-2022	28652814	171262	53796666	0.986
Eastern-2023	31115691	181957	60764678	1.000
Eastern-2024	32689723	187855	64171032	1.000
East Central-2013	42074651	177556	57617207	0.711
East Central-2014	43271065	190967	63935375	0.777
East Central-2015	46233051	205490	74709715	0.829
East Central-2016	46997561	201464	82324955	0.870
East Central-2017	44365353	199759	79674368	0.895
East Central-2018	50219374	217230	86723221	0.871
East Central-2020	52175723	235866	85680022	0.907
East Central-202	51648173	232735	93657613	0.928
East Central-2022	63384003	273966	114729688	0.945
East Central-2023	73531571	302588	135365201	0.955
East Central-2024	82998915	318960	150930785	0.932
East Coast-2013	58963093	181297	93452577	0.781
East Coast-2014	63467409	199904	110879603	0.861
East Coast-2015	62684549	211009	112757568	0.887
East Coast-2016	64603166	227047	121526796	0.928
East Coast-2017	68377220	247556	130990169	0.945
East Coast-2018	77762382	255551	149543300	0.948
East Coast-2020	85041586	277541	156903198	0.910
East Coast-2021	88300385	301921	167264942	0.934
East Coast-2022	100345838	323080	183387227	0.909
East Coast-2023	103961742	326858	200730146	0.996
East Coast-2024	112559090	358807	213367045	1.000
Northern-2013	48844076	173192	61458939	0.627
Northern-2014	50483698	178922	66911766	0.658
Northern-2015	51575321	183003	71842545	0.688
Northern-2016	47078373	165681	70697246	0.740
Northern-2017	45319282	188665	65562401	0.735
Northern-2018	47104744	199620	69392063	0.770
Northern-2020	44881286	166386	66144581	0.727
Northern-2021	50380586	166997	71459400	0.699
Northern-2022	65202823	202573	96828440	0.732
Northern-2023	77531465	229310	123615214	0.786
Northern-2024	66374329	222286	107245435	0.797
North Central-2013	56272293	134178	74046064	0.649
North Central-2014	59209736	158666	78674347	0.655
North Central-2015	58872147	161481	87428289	0.732
North Central-2016	58087459	145620	92893267	0.789
North Central-2017	52720803	138620	84639189	0.792
North Central-2018	64735292	161520	102862430	0.783

North Central-2020	53274228	144733	80092850	0.741
North Central-2021	52807779	136246	75466313	0.705
North Central-2022	66678433	174344	100498222	0.743
North Central-2023	75349692	194290	119440527	0.782
North Central-2024	87833442	210186	141407884	0.794
North Eastern-2013	12820431	37697	10419768	0.702
North Eastern-2014	12927972	37899	10692579	0.697
North Eastern-2015	9696404	37055	13010221	0.932
North Eastern-2016	9000807	37774	12922335	1.000
North Eastern-2017	9808084	38162	13968179	0.959
North Eastern-2018	11817355	39130	15536651	0.846
North Eastern-2020	11221310	36973	14372054	0.852
North Eastern-2021	12653227	42830	15807411	0.799
North Eastern-2022	13590239	46737	16133604	0.753
North Eastern-2023	14848246	50695	18701399	0.755
North Eastern-2024	14783748	49217	17402286	0.725
Northeast Frontier-2013	12304836	26784	14642296	0.785
Northeast Frontier-2014	12569289	28847	15563700	0.797
Northeast Frontier-2015	13177228	31552	17271642	0.809
Northeast Frontier-2016	13188145	31514	18677143	0.850
Northeast Frontier-2017	13282825	30222	18465336	0.837
Northeast Frontier-2018	14189099	35010	19192280	0.804
Northeast Frontier-2020	14886574	35944	18999948	0.761
Northeast Frontier-2021	16988285	38322	21740106	0.729
Northeast Frontier-2022	20217568	44850	25765332	0.688
Northeast Frontier-2023	23093891	47520	30702505	0.685
Northeast Frontier-2024	20922782	45333	29271198	0.729
North Western 2013	31988068	72221	35918082	0.557
North Western 2014	31755274	76002	39366170	0.611
North Western 2015	38417248	85250	48871257	0.627
North Western 2016	34648470	77158	47415362	0.675
North Western 2017	33049272	71739	44506236	0.664
North Western 2018	35689132	78965	46053384	0.636
North Western 2020	34506764	72676	40018412	0.572
North Western 2021	40853761	79757	48434375	0.585
North Western 2022	45708828	97521	52049373	0.561
North Western 2023	54208683	114974	68056083	0.619
North Western 2024	52469518	115863	69957371	0.657
Southern-2013	17465193	66106	24310892	0.765
Southern-2014	18006384	71642	26969890	0.799
Southern-2015	18405798	70361	29649386	0.837
Southern-2016	15582975	58026	27560260	0.937
Southern-2017	14369420	54549	25585563	0.964
Southern-2018	15485952	54495	26334618	0.913
Southern-2020	15459037	54373	26922953	0.929
Southern-2021	15760581	53134	25453040	0.875
Southern-2022	18701581	63133	30319262	0.837
Southern-2023	19397047	65896	33943459	0.879
Southern-2024	19295373	71052	35160715	0.908
South Central-2013	63235239	165706	81436128	0.635

South Central-2014	63729036	170550	89200119	0.690
South Central-2015	69404554	180011	106179419	0.754
South Central-2016	60294546	160364	99511166	0.814
South Central-2017	55301534	152780	92023588	0.820
South Central-2018	63868439	165327	106853294	0.825
South Central-2020	62508589	165062	96708057	0.763
South Central-2021	59143359	153514	89620057	0.747
South Central-2022	80005333	194206	122167332	0.753
South Central-2023	86150057	211555	140669732	0.805
South Central-2024	88189193	221569	146705561	0.820
South Eastern-2013	51550263	213442	77456400	0.785
South Eastern-2014	53456397	226654	85166730	0.833
South Eastern-2015	54683010	223990	92010691	0.847
South Eastern-2016	55712157	230383	101564026	0.907
South Eastern-2017	56532552	244329	105252832	0.941
South Eastern-2018	64151775	259292	116732880	0.917
South Eastern-2020	72951436	286285	134145161	0.930
South Eastern-2021	73493305	291110	135599082	0.938
South Eastern-2022	77961773	316476	144124673	0.959
South Eastern-2023	83141316	334635	154569374	0.968
South Eastern-2024	82095642	349945	154114597	1.000
South East Central-2013	53571724	208187	73758078	0.726
South East Central-2014	54310934	210625	80917526	0.755
South East Central-2015	56735668	222900	94652188	0.833
South East Central-2016	60295076	239157	107207475	0.885
South East Central-2017	55971399	249203	104672936	0.957
South East Central-2018	61303785	261235	115866080	0.958
South East Central-2020	67965869	253521	123226056	0.894
South East Central-2021	69741061	264552	132983083	0.940
South East Central-2022	84090601	306102	155312276	0.920
South East Central-2023	89176122	313098	172216495	0.952
South East Central-2024	88702881	332333	179892633	1.000
South Western-2013	16792857	75479	22627736	0.757
South Western-2014	20170632	81918	23320317	0.655
South Western-2015	17939258	87120	31610165	0.901
South Western-2016	16789533	78522	29234747	0.908
South Western-2017	15992746	78271	27080889	0.902
South Western-2018	15351934	81580	28779199	0.982
South Western-2020	15268884	73268	27692843	0.960
South Western-2021	16773029	75695	29443038	0.914
South Western-2022	20884342	92989	37200811	0.878
South Western-2023	22857913	102884	41038377	0.885
South Western-2024	25093470	106893	44406653	0.873
Western-2013	66786571	141113	64671153	0.477
Western-2014	61127513	138109	69228910	0.558
Western-2015	61573496	140648	80376383	0.644
Western-2016	52781345	124083	75097516	0.702
Western-2017	45755287	111890	60417989	0.651
Western-2018	53648102	124678	66070893	0.607
Western-2020	53138919	125966	53465516	0.496

Western-2021	52064335	131860	58770486	0.557
Western-2022	64272384	159390	73843804	0.566
Western-2023	72078810	177798	87347800	0.598
Western-2024	68917554	176920	83659096	0.599
West Central-2013	52719323	138992	56333805	0.527
West Central-2014	54574592	135115	60569620	0.547
West Central-2015	55271789	153666	68569187	0.612
West Central-2016	55190480	148746	76954146	0.687
West Central-2017	49737661	142318	65400033	0.648
West Central-2018	51256808	159545	73565711	0.708
West Central-2020	53678105	165968	79242557	0.728
West Central-2021	50593170	161502	79182868	0.772
West Central-2022	63052908	193787	96080604	0.751
West Central-2023	70199131	215716	112901737	0.793
West Central-2024	69750406	219829	117116509	0.828

Table 4.2 Data with Efficiency Score

4.3 INTERPRETATION OF RESULTS

Each DMU received an efficiency score ranging between 0 and 1, where:

- A score of 1.00 indicates full efficiency — the division is operating on the DEA frontier.
- A score < 1.00 indicates inefficiency — the division could increase its output (freight volume or revenue) without requiring more input.

The DEA model also identified peer units (efficient DMUs) that serve as benchmarks for inefficient divisions, along with target values for output improvement.

Visualization and Trend Analysis

To supplement the numerical DEA results, the study included graphical analyses:

- Zone-wise average efficiency table
- Heatmaps to highlight high-performing and low-performing divisions

These visual tools helped in identifying systemic patterns and divisions that consistently outperformed or underperformed over time.

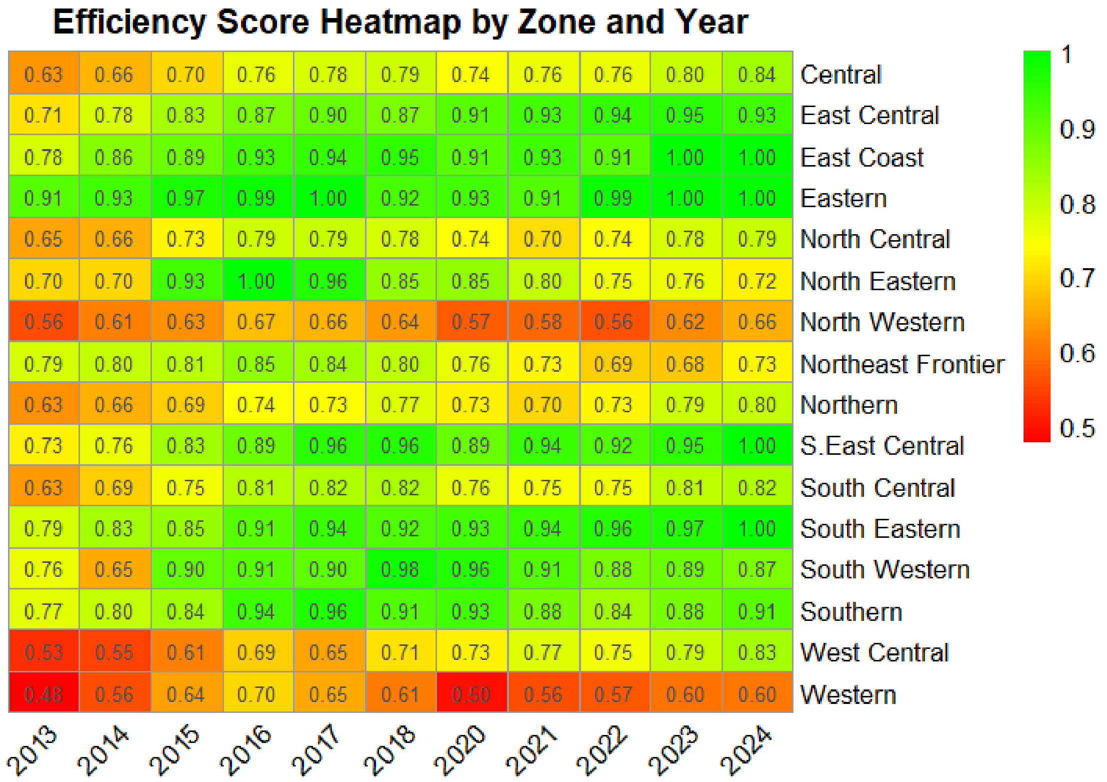

Figure 4.2 Efficiency score heatmap by zone and year

This analysis evaluates efficiency trends across 16 operational zones over an 11-year period, where lower scores indicate better performance (1.00 = optimal). The data reveals significant variations in performance stability and improvement rates, highlighting both exemplary models and areas requiring intervention.

The heatmap reveals distinct efficiency trends across India's railway zones, with clear leaders and laggards emerging. The Eastern zone stands out as the top performer, maintaining perfect efficiency scores (1.00) from 2017 onward, followed closely by the East Coast and East Central zones, which consistently scored above 0.90 in recent years. The South Eastern zone also showed impressive growth, improving from 0.79 to a perfect 1.00. In contrast, the Western and North Western zones struggled the most, with the Western zone never exceeding 0.70 and the North Western zone peaking at just 0.66. Zones like North Eastern and Northeast Frontier displayed concerning declines after initial gains, possibly due to infrastructural or operational challenges. Meanwhile, the South Western zone exhibited high volatility, with scores fluctuating sharply before stabilizing. Overall, while most zones demonstrated gradual improvements, significant regional disparities persist, highlighting the need for targeted policy interventions in underperforming regions to achieve uniform efficiency across India's railway network.

CHAPTER 5

CONCLUSION

CHAPTER 5

5.1 FINDINGS

The efficiency analysis Indian Railways' freight divisions from 2013 to 2024 reveals clear patterns of zonal performance, both over time and across regions. Zones such as South East Central Railway (SECR), South Eastern Railway (SER), East Coast Railway (ECoR), and South-Central Railway (SCR) consistently appear in green, indicating high DEA efficiency scores—often above 0.90 and frequently close to 1.00. These zones have emerged as benchmark performers, showcasing sustained operational efficiency across the decade.

The reasons for their superior performance are rooted in their strategic geographic positioning, high freight density, and well-developed infrastructure. For instance, South East Central and East Coast Railways are rich in bulk commodity flows, especially coal, iron ore, and steel, which form a significant portion of Indian Railways' freight revenue. These zones are connected to major ports, industrial corridors, and power plants, enabling high NTKM output with efficient asset utilization. Additionally, zones like SECR benefit from relatively flat terrain and minimal passenger congestion, allowing for uninterrupted freight train operations and faster wagon turnaround times.

In contrast, zones such as North Eastern Railway (NER), Northeast Frontier Railway (NFR), and West Central Railway (WCR) consistently score lower, as represented by yellow to red tones on the heatmap. These zones often fall below the 0.70 efficiency threshold in several years, indicating suboptimal performance. The causes of inefficiency in these regions are typically structural and geographical. Northeast Frontier and North Eastern zones face terrain-related challenges, including hilly landscapes, frequent natural disruptions, and limited double-line or electrified tracks.

These regions also have lower freight density due to limited industrial development compared to other zones, making it difficult to fully utilize wagon capacity.

Zones like Western Railway (WR) and North Western Railway (NWR) exhibit moderate and fluctuating efficiency scores, typically ranging between 0.60 and 0.80. While these zones do handle substantial freight traffic, they also face high passenger traffic congestion, especially in urban corridors, which affects freight scheduling and speeds. Moreover, dependence on commodities with lower revenue-to-weight ratios and delayed modernization projects may be contributing factors to their middling performance.

An important insight from the heatmap is the overall upward trend in efficiency scores in 2022 and 2023 across most zones. This likely reflects post-pandemic recovery efforts, improved digital integration (such as e-RD and FOIS), and a stronger push toward freight corridor development. For example, Dedicated Freight Corridors (DFCs), even in partial operation, may have started easing the load on conventional lines in zones like East Central and Northern Railways.

However, a slight dip in scores in 2024 for zones like West Central and Western indicates the need for continuous performance monitoring, infrastructure upgrades, and perhaps a reassessment of freight handling strategies.

In summary, the heatmap not only provides a zonal and temporal snapshot of freight efficiency but also highlights how economic geography, infrastructure investment, commodity patterns, and operational management collectively influence freight performance across the Indian Railways network.

5.2 SUGGESTIONS

Drawing on the conclusions based on the DEA analysis of Indian Railways' freight divisions, some practical recommendations are put forward to improve operational performance and minimize efficiency differences across divisions. The recommendations aim at enhancing both strategic planning and implementation in the railway freight system.

Divisions that always recorded high efficiency ratings should be used as models by other regions. Underperforming divisions are urged to learn and emulate best practices from these high-performing peers, specifically in terms of wagon usage, terminal turnaround, and freight customer management. This strategy increases internal knowledge sharing and a culture of performance excellence.

It is suggested that Indian Railways make division-level efficiency reviews a habit using DEA. Efficiency scores as part of routine performance monitoring will give division managers actionable information about their operational position. Efficiency scores can be used as quantifiable measures of performance to inform strategic interventions.

Some areas, especially in the central and north-east regions of the nation, had consistently low efficiency ratings. These inefficiencies can be due to infrastructure bottlenecks, inadequate exposure to high-density freight, or geographic factors. To resolve these issues, focused investment into terminal infrastructure, track upgrades, and private freight terminals should be a priority. DEA findings can inform data-driven decisions for fair infrastructure investments.

There is also an urgent need to enhance digital integration and data availability. Decision-making operational can be improved through more integration of current digital platforms like FOIS and performance dashboards, complemented by DEA-based analysis. Immediate access to efficiency indicators can underpin timely decision-making and minimize the generation of operational delays.

Additionally, enhancing human capability is crucial. Regular training and sensitization workshops for divisional managers and terminal managers will assist in aligning their decision-making with evidence-based strategies. DEA outcomes can be integrated into case studies and performance simulations to develop operational capability.

The DEA models of the future must include further variables, such as environmental effects and cost measures. That way, Indian Railways can assess its freight business not just in terms of production but also in relation to wider objectives like sustainability, cost-effectiveness, and carbon-neutrality. Creating a multi-faceted efficiency model would more accurately reflect the complexities of contemporary logistics.

Lastly, Indian Railways should establish a centralized decision support system that dynamically evaluates DEA, constantly updates benchmarks, and offers actionable intelligence to improve operations. Such a system will formalize data-driven governance and help Indian Railways transform into a more nimble and efficient logistics provider.

These recommendations, based on empirical analysis and procedural knowledge of operational environments, present a way toward a more productive, robust, and sustainable freight network in Indian Railways.

5.3 CONCLUSION

This study employed Data Envelopment Analysis (DEA) to evaluate the freight performance of various divisions within the Indian Railways over a period of ten years. By utilizing an output-oriented Variable Returns to Scale (VRS) model, the efficiency of each division was assessed based on inputs such as Net Tonne Kilometres (NTKM) and outputs like freight volume and revenue.

The findings revealed significant variations in efficiency across the divisions and years. While some divisions consistently operated on the efficiency frontier, others showed substantial potential for improvement. Benchmarking helped identify target output levels and peer comparisons, providing actionable insights into how inefficient divisions could realign their operations to match top performers.

The analysis highlights not only the performance disparities but also the dynamic nature of freight operations influenced by infrastructure, demand patterns, and regional specializations. High-performing divisions such Eastern division serve as benchmarks and can provide best practices in logistics, asset utilization, and service optimization.

In conclusion, this research offers a data-driven foundation for performance improvement in the freight sector of Indian Railways. It supports managerial decision-making and policy formulation aimed at improving the cost-effectiveness and service quality of the freight network. Future studies may incorporate environmental metrics, multi-stage DEA, or stochastic frontier analysis to build upon this foundational work.

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