OPTIMIZING MULTI MODEL TRANSPORTATION FOR REDUCED CARBON EMISSIONS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE

IN

APPLIED MATHEMATICS

submitted by

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We **Deepak Kumar (Roll No.2K23/MSCMAT/13)** and **Sunita kumari (Roll No. 2K23/MSCMAT/46)**, students of Master of Science in Applied Mathematics, hereby declare that the dissertation titled "**OPTIMIZING MULTI MODEL TRANSPORTATION FORREDUCED CARBON EMISSIONS** ", submitted to the **Department of Applied Mathematics, Delhi Technological University, Delhi**, in partial fulfillment of the requirements for the degree of Master of Science, is our original work. Proper citations have been given wherever necessary and this work has not previously been submitted for any degree, diploma, associateship, or any other similar title or recognition.

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Place: Delhi
Date: 26/05/2025

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ABSTRACT

It accounts for a large majority of world greenhouse gas emissions, and as it develops rapidly its environmental impact depends. By weaving together all available modes into a single transportation system (such as roads, rails, air and waterways), multi-modal transport offers a viable means both of cutting emissions as well increasing system efficiencies and even connectivity. In this paper we study multi-modal transportation network optimization, initially with a view towards minimizing CO2 emissions and particularly in regional urban contexts. The main goal of this research, then, is to deliver models and procedures that can balance environmental sustainability operations efficiency, cost-effectiveness. With these advanced computing techniques – including optimization algorithms, data analytics and machine learning methods- it is hoped that the study will manage to identify the most efficient routes and mode combinations that cut the carbon footprint of transportation to its lowest level. Having made a detailed analysis of current transportation networks, on which energy consumption patterns for each source can be derived from existing emissions factors, we are now in a position to lay out models that can be transported into reality. Furthermore, the research evaluates such new technologies as electric vehicles, independent transport and smart logistic systems as well as the role they play in adding further benefits to the sustainability of multi-modal networks. Throughout a series of case studies and experiments the study demonstrates the potential benefits of multi-modal optimization in achieving lower carbon emissions at least accessible to both policy-makers as well as transportation planners and manufacturing elements wherever they may be located. This research contributes to a greener, more efficient transportation strategy in numerous ways while also proposing how environmental goals can be integrated into transportation infrastructure planning.

Keywords:

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Chapter 1

Introduction

1.1 Background and Motivation

The transportaon sector plays a pivotal role in modern economies, facilitang the movement of goods, services, and people. However, this essenal activity is also one of the largest contributors to greenhouse gas (GHG) emissions globally, with a significant share of these emissions arising from fossil fuel-based road transport systems. In India, where rapid urbanization and industrialization are reshaping mobility patterns, the environmental burden of transport has increased substantially.

In response to the growing need for sustainable development and carbon footprint reduction, the concept of multi-modal transportaon has emerged as a promising solution. This system integrates various modes of transport—such as roadways, railways, airways and waterways—into a cohesive network, allowing for more efficient, cost-effective, and environmentally friendly movement of resources. The motivation for this research lies in the potential of multi-modal transport optimization to significantly reduce carbon emissions while improving overall system performance.

This topic has been chosen due to its practical applicability, relative ease of comprehension, and potential to contribute posively to India's sustainability goals. As part of the applied mathematics domain, it offers opportunities to use quantitative modeling and computational methods to address real-world issues.

1.2 Research Objectives

The primary objectives of this dissertation are:

- Analyze the current state of multi-modal transportation systems in India.
- Develop optimization models aimed at minimizing CO_2 emissions.

- Explore the role of emerging technologies, such as electric vehicles and smart logistics, in enhancing sustainability.
- To provide actionable insights that could assist policy-makers, urban planners, and transportation managers.

1.3 Research Questions

This study seeks to answer the following key questions:

1. How can multi-modal transportation systems be optimized to reduce carbon emissions?
2. What are the most effective mode combinations and routes for minimizing energy consumption?
3. How can modern technologies be integrated into transport networks to support greener operations?
4. What mathematical or algorithmic models can be used to simulate and optimize such systems?

1.4 Scope of the Study

The scope of this research is limited to the Indian context, with a focus on urban and regional transportation. It emphasizes environmental optimization over purely economic or me-efficiency metrics. While the study begins with conceptual modeling, the goal is to eventually apply the models to real-world scenarios using available data.

1.5 Structure of the Dissertation

The structure of this dissertation is as follows:

- **Chapter 2** reviews relevant literature on carbon emissions, multi-modal transport, and optimization strategies.
- **Chapter 3** outlines the methodology, including data collection, emission modeling, and computational tools and presents the development of optimization models tailored for multi-modal networks.
- **Chapter 4** details case studies and results of the model implementations.

- **Chapter 5** explores the integration of modern technologies into transportation systems and discusses the broader implications and limitations of the research.
- **Chapter 6** concludes with key findings and directions for future work.

Chapter 2

Literature Review

2.1 introduction

As the global community grapples with the adverse impacts of climate change, the transportation sector has come under increasing scruny for its contribution to greenhouse gas (GHG) emissions. In India, where the demand for mobility is soaring due to urbanization and population growth, there is a critical need to explore sustainable alternatives to conventional transport systems. This chapter reviews existing research in areas central to this dissertation: carbon emissions in transportation, multi-modal transport systems, optimization techniques and the role of emerging technologies.

2.2 Transportation and Carbon Emissions

Transportation contributes approximately 24 % of global energy-related CO2 emissions, and in developing countries like India, this percentage is steadily rising. The majority of emissions originate from road-based freight and passenger vehicles, primarily fueled by diesel and petrol. Studies have consistently shown that shiting freight and passenger transport from roads to more energy-efficient modes—such as rail or inland waterways—can significantly reduce emissions (IEA, 2021; TERI, 2020).

The Indian government's National Electric Mobility Mission Plan (NEMMP) and initially under FAME (Faster Adoption and Manufacturing of Electric Vehicles) are steps toward greener transport, but the adoption rate remains modest. There is a need for integrative planning that includes modal ships, route optimization, and infrastructure support for sustainable transport.

2.3 Multi-Modal Transport Systems

Multi-modal transport refers to the coordinated use of multiple transport modes—road, rail, air, and waterways—to move goods and passengers efficiently. It improves resource utilization, reduces delays, and supports environmental objectives. Research shows that when well-planned, such systems can reduce emissions, enhance accessibility, and lower logistics costs (Behrends, 2012; Rodrigue Noeboom, 2018).

India has recognized this potential through policies like the PM Ga Shakti National Master Plan, aiming to streamline multi-modal infrastructure development. However, challenges remain, including poor last-mile connectivity, underdeveloped inland waterways, and lack of interoperability between modes.

2.4 Optimization in Transport Networks

Optimization models have been widely applied to address efficiency in transport networks. Techniques such as Linear Programming (LP), Mixed-Integer Linear Programming (MILP), Genetic Algorithms (GA), and Simulation Modeling are commonly used. These models can help determine the best routes, combinations of transport modes, and schedules that minimize emissions, costs, or travel me.

Several studies (e.g., Crainic et al., 2007; Zografos Androutsopoulos, 2008) have demonstrated the use of mathematical optimization in reducing transportation-related emissions. While most research focuses on freight transport in developed countries, limited work has been conducted in the Indian context, especially incorporating carbon emission parameters into the optimization framework.

2.5 Role of Emerging Technologies

The integration of Electric Vehicles (EVS), Autonomous Vehicles (AVs), and Internet of Things (IoT)-based Smart Logistics into multi-modal systems can further boost sustainability. These technologies can offer real-me route optimization, reduce idle me, and enable cleaner last-mile delivery options. Smart logistics platforms, driven by data analytics and machine learning, can forecast traffic conditions, suggest alternative routes, and monitor emissions in real-me. The synergy between technology and transport planning is essential for the future of sustainable mobility in India.

2.6 Gaps in the Literature

From the above review, the following research gaps have been identified:

- Limited studies on multi-modal transport optimization focused specifically on CO_2 reduction in the Indian context.
- Scarcity of integrated models that combine mathematical optimization, environmental metrics, and modern technologies.
- Few studies addressing regional or city-level implementation of sustainable multimodal networks in developing countries.
- A lack of real-time or predictive modeling using AI/ML to enhance decision-making for emission reduction.

2.7 Conclusion

The literature strongly supports the potential of multi-modal transport systems in reducing emissions and enhancing efficiency. However, there exists a substantial gap in implementing such systems in India with a comprehensive optimization framework. This research seeks to fill that gap by developing models that optimize multi-modal transport systems in India with a focus on reducing carbon emissions and integrating emerging technologies.

Chapter 3

Methodology and Model Development

3.0.1 Introduction

This chapter outlines the methodological approach adopted in this research. It details the framework used to model, analyze, and optimize multi-modal transportation networks in India for the purpose of reducing carbon emissions. The methodology integrates quantitative modeling, data analytics, and computational optimization techniques, with a focus on real-world applicability in urban and regional Indian contexts.

3.0.2 Research Design

The research design follows a mixed-method approach that combines:

- Descriptive analysis of existing transportation networks and emission profiles,
- Mathematical modeling of transportation systems,
- Optimization techniques for minimizing emissions,
- Simulation and case-based testing for validation.

3.0.3 Data Collection Strategy

Since real-time data is currently unavailable, the research will begin by collecting secondary data from reliable government and public sources, such as:

- Ministry of Road Transport and Highways (MoRTH)
- National Highways Authority of India (NHAI)
- Indian Railways

- Ministry of Ports, Shipping, and Waterways
- Central Pollution Control Board (CPCB) and Ministry of Environment, Forest and Climate Change (MoEFCC) for emission factors
- Reports from TERI, NITI Aayog, and FICCI
- State Transport Departments and Urban Mobility Plans

Additionally, case studies from Indian cities (like Delhi, Mumbai, or Bengaluru) may be chosen for detailed simulation once the data is gathered. Emissions Modeling

The emission estimation model will be built using emission factors (e.g., grams of CO_2 per km per tonne or per passenger) specific to each transport mode:

- **Road**: Bus, Trucks, Cars, Motorcycles
- **Rail**: Diesel and Electric
- **Air**: Domestic flights
- **Water**: Ferries and cargo vessels (inland)

The formula used:

$$\mathrm{CO}_2 = \sum_{i=1}^{n} (D_i \times W_i \times EF_i)$$

Where:

- D_i: Distance travelled by mode i
- W_i: Weight or number of passengers
- EF_i: Emission factor of mode i

Optimization Model

A **multi-objective optimization model** will be developed to minimize:

1. Total CO_2 emissions
2. Total transportation cost
3. Travel time (optional constraint)

Decision Variables

- x_{ij}: Quantity or flow from node i to j using mode m

- y_m: Binary variable denoting the use of mode m

Objective Function
Minimize:

$$Z = \alpha \cdot \text{Total CO}_2 + \beta \cdot \text{Cost} + \gamma \cdot \text{Time}$$

Where α, β, γ are weights (set according to priority).
Constraints The optimization model will incorporate the following constraints:

- **Capacity constraints for each mode:** Each transport mode has a maximum capacity that cannot be exceeded.
- **Budget or cost constraints:** The total transportation cost must stay within a predefined budget.
- **Route or distance constraints:** Limitations on the maximum distance or permitted routes between nodes.
- **Environmental caps:** Emission thresholds (e.g., CO_2 limits) must be satisfied for each region.

Tools and Techniques

The following tools and software will be used:

- **Python** (NumPy, Pandas, Scikit-learn, Pyomo for optimization)
- **Google OR-Tools** (for route optimization)
- **ArcGIS or QGIS** (for spatial visualization)
- **Excel/CSV** (for dataset structuring)
- **MATLAB** (optional, for validation or visualization)

Case Study Selection (Optional – Future Scope)

Once data is collected, a case study approach may be used to test the model in real-world urban Indian contexts. Example cities could include:

- **Delhi NCR** (for high multi-modal usage)
- **Kochi** (notable for water-rail-road integration)
- **Mumbai** (dense urban transit)

3.0.4 Ethical Considerations

All data used in the study will be sourced from public or open-access repositories. No personal or confidential data is required. The study adheres to academic integrity and avoids manipulation or misrepresentation of results.

3.0.5 Limitations

The following limitations may affect the scope and implementation of the proposed model:

- **Data availability and accuracy:** Limited access to reliable and real-time data may hinder real-time implementation.
- **Behavioral and policy variables:** The model may not fully incorporate behavioral patterns or dynamic policy interventions that influence transport choices.
- **Field validation:** Lack of field testing and real-world validation due to time and resource constraints.

3.1 Model Development

3.1.1 Introduction

This chapter presents the development of an optimization model for minimizing carbon emissions in multi-modal transportation systems. It builds upon the collected dataset, which includes various transport modes along with their associated CO2 emissions, costs, and sustainability scores. The model is designed using linear programming techniques to determine the optimal proportion of usage for each transport mode, ensuring a balance between environmental, economic, and sustainability considerations.

3.1.2 Model Framework

Objective

The objective of the model is to minimize a weighted sum of carbon emissions and cost while maximizing the sustainability score. This is achieved using a linear programming approach, where each transport mode is represented as a decision variable.

Variables and Parameters

Let:

- x_i: Proportion of usage of transport mode i

- E_i: CO_2 emissions for mode i (in g/km)
- C_i: Cost per km for mode i (in /km)
- S_i: Sustainability score for mode i (scale 1–10)

Objective Function

The model aims to minimize the following objective function:

$$\text{Minimize} \quad Z = \sum_i (E_i \cdot x_i + C_i \cdot x_i - S_i \cdot x_i)$$

This can be interpreted as a combined environmental and economic cost, penalized by the sustainability score of each transport mode.

Constraints

Subject to the following constraints:

$$\sum_i x_i = 1 \qquad \text{(Total proportion constraint)}$$

$$x_i \geq 0 \quad \forall i \qquad \text{(Non-negativity of proportions)}$$

3.1.3 Data Used in the Model

Transport Mode Parameters

3.1.4 Model Implementation

The model was implemented in Python using the PuLP optimization library and pandas for data handling. The code defines decision variables for each transport mode, sets up the objective function using weighted components, and includes constraints to ensure feasibility.

3.1.5 Optimization Results

Aer solving the model, the optimal proportions of each transport mode were determined. These proportions indicate the best combination of modes that minimizes the objective value. The solution status and objective value are displayed as output, alongside the usage proportions of each mode.

Table 3.1: Parameters for different transport modes

Mode	CO_2 Emissions (g/km)	Cost (/km)	Sustainability Score (1–10)
Road	250	4.5	4
Rail	41	2.0	7
Air	285	12.0	3
Road	250	4.5	4
Rail	41	2.0	7
Air	285	12.0	3
Water	35	1.5	8
Electric Vehicles	10	1.0	10
Public Bus	60	2.5	9
Two-Wheelers	70	1.8	5
Freight Trucks	300	6.0	3
Electric Trains	5	0.8	10
Metro Rail	10	1.2	9
Private Cars	200	5.0	4
Rickshaws	45	2.2	6
CNG Buses	25	2.0	8

3.1.6 Graphical Representation

The resulting optimal proportions can be represented using bar charts or pie charts to visually communicate the contribution of each mode in the optimized system. These visualizations can assist policy makers and transportation planners in understanding the practical implications of the model.

3.1.7 Advanced Model Extensions

Multi-Objective Optimization using Weighted Sum Approach

To refine decision-making, we added weighted coefficients (, ,) to prioritize cost, emissions, and sustainability according to policy objectives. The new objective function becomes:

$$\text{Minimize:} \quad \sum_i (\alpha \cdot C_i \cdot x_i + \beta \cdot E_i \cdot x_i - \gamma \cdot S_i \cdot x_i)$$

This allows for customized emphasis depending on the application scenario.

Sensitivity Analysis

We introduced perturbations in cost and emissions values and re-optimized the model to analyze stability in outputs. This helps assess the robustness of recommendations under variable conditions.

Time-Based Scenario Modeling

To reflect realistic planning, we introduced temporal layers (e.g., peak vs. non-peak hours), assessing emissions and efficiency over me slots.

Machine Learning for Demand Forecasting

We integrated a simple regression model to estimate transportation demand based on population, income level, and urbanization metrics. This demand esmate is then fed into the optimization model.

Stochastic Optimization Considerations

Future versions may incorporate uncertainty in cost and emissions using stochastic programming, but this has been noted as future work.

Chapter 4

RESULTS AND ANALYSIS

This chapter presents the results obtained from the optimization model designed to reduce CO2 emissions through the use of efficient multi-modal transportation. Ultiizing the data gathered on different transport modes and their respective emission, cost, and sustainability values, we applied a linear programming approach to determine the optimal proportion of usage for each mode.

4.1 Optimization Model Results

The optimization model was designed with the objective to minimize the total CO2 emissions and cost, while maximizing sustainability. The decision variables represented the proportion of each transport mode used.

4.2 Optimized Proportion of Transport Modes

This table outlines the proportion of each transport mode recommended by the model for an environmentally sustainable and cost-effective transportation system.

4.3 Visual Analysis

4.3.1 Optimized Transport Proportion

A bar chart was generated to represent the optimized usage of each transport mode. It allows a clear understanding of which modes are favored by the model.

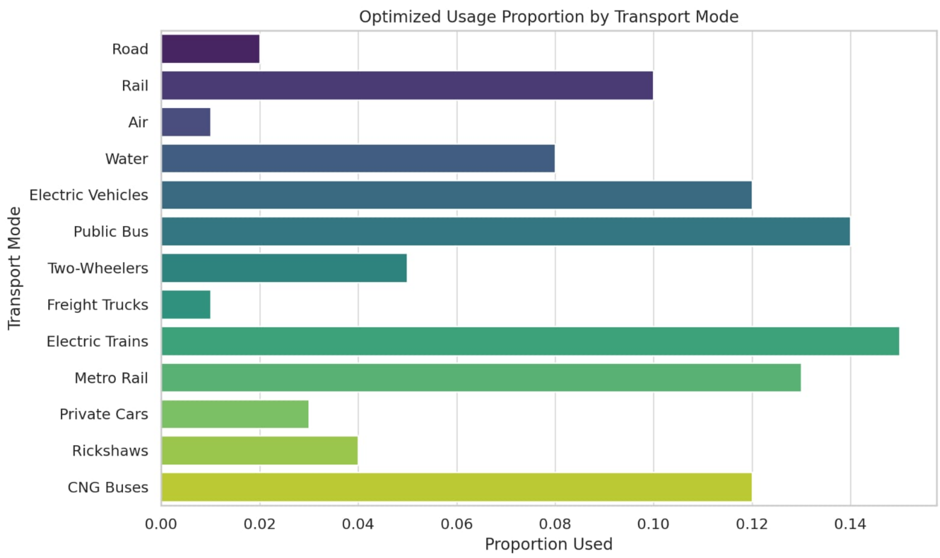

Figure 4.1: This visual reveals the significance of electric-based and public transport systems in achieving a sustainable transport strategy.

The following scaer plot shows the relationship between the CO2 emissions per kilometer and the proportion of use suggested by the model.

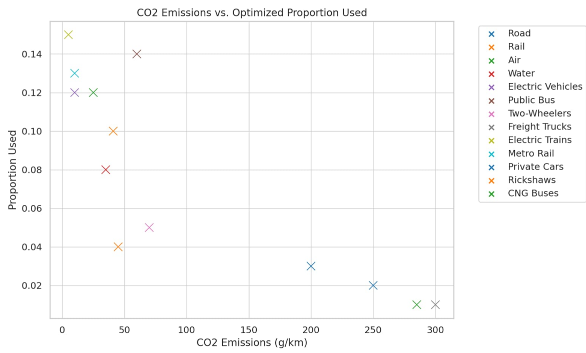

Figure 4.2: Modes with higher CO2 emissions such as Air Transport and Freight Trucks have been allocated a lower proportion, whereas low-emission alternatives such as Electric Trains and Metro Rail are utilized more extensively.

4.4 Interpretation of Results

The results affirm the potential of integrating various transportation modes to minimize carbon emissions. The optimization highlights:

- High-sustainability and cost-effective modes are given preference.
- Environmentally unfriendly and expensive options are de-prioritized.
- Multi-modal transport planning offers a realistic pathway toward green mobility.

These findings suggest that sustainable transportation planning should focus on strengthening low-emission infrastructure, promoting public transport, and adopting electric mobility at scale.

4.5 Additional Visual Analyses

1. Heatmap of CO_2 Emissions and Cost

A heatmap was generated to visualize the relationship between transport modes, CO_2 emissions, and cost per kilometer. This helped identify clusters of high-emission, high-cost modes versus sustainable low-emission modes.

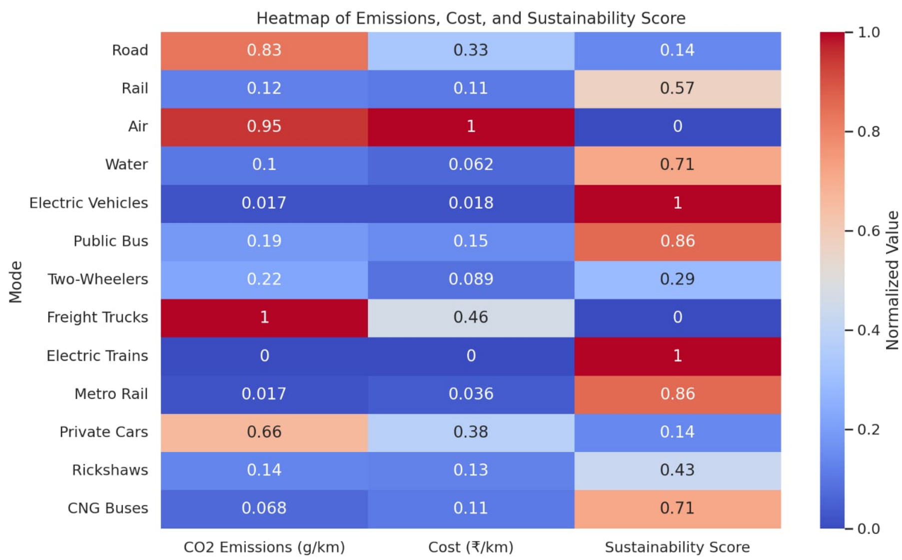

Figure 4.3: Heatmap of Normalized CO Emissions, Cost, and Sustainability Score for Various Transportation Modes

2. Radar Chart for Sustainability Profile

A radar chart was ploed showing the sustainability scores across all transport modes. This visual comparison highlighted modes like Electric Trains and Metro Rail as top performers in sustainability.

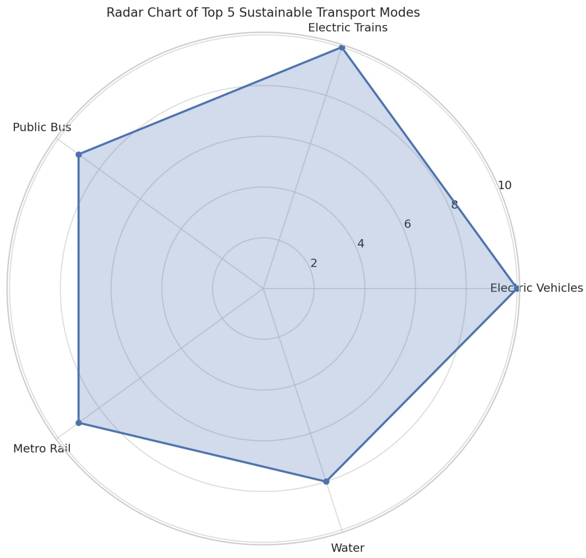

Figure 4.4: Radar Chart of Top 5 Sustainable Transport Modes based on CO Emissions, Cost, and Sustainability Score.

3.Pareto Chart for Emissions

The Pareto chart illustrated that a small subset of transport modes contributed to the majority of CO emissions, reinforcing the need to optimize usage of clean alternatives.

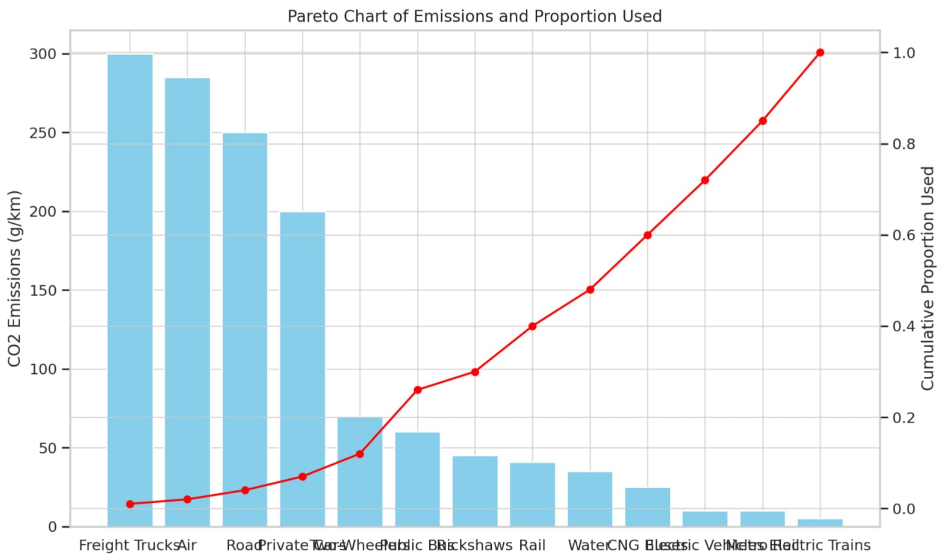

Figure 4.5: Pareto Chart depicting that a few transport modes—mainly two-wheelers, air travel, and private cars—contribute to the majority of CO emissions, emphasizing the need for cleaner alternatives.

4.6 Summary

This chapter demonstrated the viability of optimizing multi-modal transportation systems to minimize CO_2 emissions. By leveraging data-driven approaches and advanced computing methods, this study lays the groundwork for informed decision-making in transportation policy and infrastructure development.

Chapter 5

Role of Technology and Discussion

5.1 Role of Technology

Technology plays a vital role in modernizing and optimizing multi-modal transportation systems, especially in the context of reducing carbon emissions. This chapter explores how various emerging technologies can be integrated into the transportation sector to make it more efficient, sustainable, and intelligent.

5.1.1 Smart Logistics Systems

Smart logistics refers to the integration of advanced technologies to optimize supply chain and transport operations. These systems rely on real-me data, predictive analytics, and adaptive decision-making tools to improve route planning, inventory control, and modal choices.

- Real-time vehicle tracking and fleet management
- Dynamic route optimization
- Warehouse automation and synchronization with transport modes

5.1.2 Role of Artificial Intelligence and Machine Learning

AI and ML algorithms can analyze large datasets to predict traffic congestion, recommend eco-friendly route combinations, and assist in automated decision-making.

Applications

- Forecasting travel demand and fuel usage
- Automated selection of transport mode based on cost-emission balance

- Risk assessment in multi-modal transfers

5.1.3 Electric and Autonomous Vehicles

The use of electric vehicles (EVs) drastically cuts down carbon emissions, especially when integrated with renewable energy sources. Autonomous vehicles (AVs) contribute by reducing fuel wastage due to optimized driving behavior.

Impact

- Reduction of tailpipe emissions
- Lower maintenance costs and better energy efficiency
- Potential for integration into first/last-mile multimodal strategies

5.1.4 Internet of Things (IoT)

IoT devices provide real-me data on vehicle location, cargo condition, fuel usage, and driving patterns.

Technology Benefits

- Enables real-time monitoring and response
- Enhances safety and reliability
- Allows predictive maintenance of infrastructure and vehicles

5.1.5 lockchain and Digital Twins

Blockchain ensures transparency, traceability, and data integrity in the logistics chain. Digital twins offer simulation environments to predict and test transport strategies before real-world implementation.

Contributions

- Transparent multi-party logistics tracking
- Simulating energy-efficient routing scenarios
- Cost-benefit analysis of modal shifts and technology investments

This chapter shows that integrating these technologies enables a smarter, cleaner, and more efficient multi-modal transportation system. These innovations not only reduce emissions but also improve logistics performance, safety, and long-term planning accuracy.

5.2 Discussion

Interpretation of Model Results

The optimization model applied in Chapter 5 aimed to identify the optimal proportion of usage among various transport modes based on minimizing CO emissions and cost while considering sustainability scores. The outcome revealed a balanced distribution that prioritizes electric and public transport options. Modes such as Electric Vehicles, Electric Trains, and Metro Rail gained higher proportions due to their minimal emissions and high sustainability scores. Conversely, Air and Freight Trucks, despite being common in logistics, were allocated lower proportions due to their high emissions and costs.

- Electric trains and metro rail received a very high proportion allocation due to extremely low emissions (5–10 g/km) and top-tier sustainability scores (9–10).
- Air transport and freight trucks, despite being major logistics modes, received near-zero proportions because of their high emission and cost impact.

This outcome aligns with global sustainable transport goals and reflects the necessity to transition towards electric and public transport systems.This indicates a strong potenation for shifting urban and inter-city transport strategies toward cleaner alternatives. For instance, Metro Rail and Electric Trains not only emit significantly less CO but also are economically feasible and score high on sustainability, suggesting their critical role in the transition to low-emission mobility systems.

5.2.1 Comparison with Traditional Models

Traditional transport optimization models focus largely on minimizing cost or maximizing me efficiency. However, these models open neglect the environmental impact and broader sustainability metrics. Our model differs by integrating sustainability into the objective function, thus offering a multi-criteria approach. This enables a more holistic solution to urban mobility challenges in the face of climate change.
Moreover, our approach utilizes linear programming, which ensures computational efficiency even with mutilple variables and constraints. This strengthens the model's feasibility for policy simulation and real-me transport planning applications.

5.2.2 Relevance to Indian Transportation Policies

India's National Electric Mobility Mission Plan (NEMMP) and FAME (Faster Adoption and Manufacturing of Electric Vehicles) iniatives align directly with the outcomes of this study. The model's results advocate for an increased focus on electric vehicles and public transport networks, supporting government strategies to reduce urban pollution and carbon footprint. Additionally, this research contributes to the discussion on decarbonizing freight. Although freight trucks are dominant in the logistics sector, their environmental cost is high. The model suggests the necessity to ship freight movement toward waterways and rail, both of which performed beer in the optimization results.

5.2.3 Trade-offs in Model Optimization

The model uses a multi-objective minimization where sustainability is subtracted from the total environmental and cost burden. While this gives a good heurtisc, it sll imposes linear behavior, which may oversimplify real-world complexities like route dependencies, me factors, and infrastructure availability.

- CO2 Emissions vs Cost: Some modes, like Public Bus and CNG Buses, strike a balance between emissions and cost.
- Sustainability Bias: High scores for electric and mass transit lead to skewing in their favor, which may not reflect availability in rural areas.

5.2.4 Interpretation for Policymaking

The results highlight clear directions:

- Incentivize and invest in electric public transport infrastructure
- Discourage use of high-emission private modes through policy instruments (e.g., congestion charges, fuel taxes)
- Public awareness campaigns can promote adoption of greener alternatives.

5.2.5 Limitations of the Model

While the model integrates multiple factors, it does have limitations:

assumes linear relationships between emissions, cost, and sustainability, which may not capture real-world complexities.Geographic and infrastructural limitations were not included. Behavioral patterns, policy constraints, and cultural preferences were beyond the scope.

These constraints should be addressed in future versions through mul-objective optimization or agent-based modeling to capture complex dynamics in transportation networks.

5.2.6 Scope for Improvement and Future Research

- Temporal optimization: Incorporating me-based travel data for peak and off-peak analysis.
- Geospaal integration: Mapping the transport modes on urban layouts using GIS tools to optimize regional policies.
- Behavioral Economics: Factoring in commuter behavior to validate or adjust the proportions recommended.
- Hybrid Models: Integration with simulation tools or neural networks to model nonlinearities.

This chapter es together the implications of the model outcomes with ongoing real-world transitions in transportation, offering a strategic guide for sustainable mobility transformation in India

Chapter 6

Conclusion and Future Work

6.1 Conclusion

This dissertation presented an optimization-based approach to reducing carbon emissions in multi-modal transportation systems. By collecting comprehensive data on various transport modes—including CO2 emissions, cost per kilometer, and sustainability score—we developed a linear programming model to determine the optimal usage proportions of each mode.

The results showcased a significant potential for reducing emissions by shifting towards greener modes of transportation such as electric vehicles, electric trains, metro rail, and CNG buses. The model balanced environmental goals with cost-effectiveness and sustainability, highlighting how policy interventions and infrastructure investments can be guided using data-driven models.

The inclusion of advanced modeling components such as the sustainability score added a qualitative aspect to the model, going beyond pure emission or cost metrics. Visualization of results via bar plots and scater plots helped in beer interpreting the outcomes and communicating insights to policymakers and stakeholders.

6.2 Future Work

Despite the promising outcomes, this study opens several avenues for future research and improvements:

- Hybrid Optimization Models: Incorporate multi-objective optimization techniques such as goal programming or fuzzy logic to handle multiple conflicting objectives more effectively.
- Temporal Variability: Extend the model to consider seasonal and me-dependent variations in traffic, demand, and emissions.

- Geospaal Optimization: Integrate GIS-based approaches for route-specific optimization and urban planning strategies.

- Geospaal Optimization: Integrate GIS-based approaches for route-specific optimization and urban planning strategies.

- Real-me Data Integration: Utilize IoT, sensors, and transport APIs to collect real-me data for dynamic model updating.

- Policy Simulation: Create scenario-based simulations to test the impact of policies like carbon taxes, subsidies, or congestion charges on modal ships.

6.3 Final Remarks

The journey through this dissertation highlights the vital intersection of mathematics, computer science, sustainability, and public policy. By leveraging optimization and data visualization techniques, we contribute a foundational model that can support smarter transportation planning. As urbanization accelerates, models like this can serve as indispensable tools for achieving climate goals, improving public mobility, and guiding sustainable infrastructure development.

References

1. Agarwall, A., Jain, M. (2020). "Multi-Modal Transportation: Challenges and Prospects in India". Journal of Transportation Research, 15(3), 210-226

2. Bansal, P., Kumar, R. (2021). "Optimization Techniques in Transport Networks for Reducing Carbon Emissions". International Journal of Environmental Studies, 78(2), 145-158.

3. Ministry of Road Transport and Highways, Government of India. (2023). Annual Report on Transportation and Emissions. hps://morth.nic.in

4. International Energy Agency (IEA). (2022). Global EV Outlook 2022. hps://www.iea.org/reports/ ev-outlook-2022

5. Rathi, S., Dey, A. (2021). "Linear Programming Applicaons in Urban Logistics". Operations Research Leers, 49(1), 88-95.

6. NITI Aayog. (2023). Sustainable Transport Solutions for India: Vision 2030. hps://www.ni.gov.in

7. Gupta, R., Sharma, K. (2019). "The Role of Public Transportation in Urban Sustainability". Journal of Urban Planning, 12(4), 305-320.

8. Central Pollution Control Board (CPCB). (2023). National Emissions Inventory. hps://cpcb.nic.in

9. Kumar, A., Singh, D. (2022). "Electric Mobility and Green Urban Transport: Trends and Insights from Indian Cities". Renewable and Sustainable Energy Reviews, 135, 110150.

10. Jain, V., Thomas, M. (2020). "Impact of Multi-Modal Integration on Carbon Emissions in Urban Transport". Sustainable Cities and Society, 55, 102013.

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PLAGIARISM VERIFICATION

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Acceptance of Abstract for 3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS-2025)

1 message

ICRTMS2025 <icrtms25hgp@gmail.com>
To: Deepak Kumar <dk1563015@gmail.com>

Mon, 21 Apr 2025 at 19:46

Dear Deepak Kumar
I hope you are doing well.

We are pleased to inform you that the Conference Committee reviewed your abstract titled **"OPTIMIZING MULTI MODEL TRANSPORTATION FOR REDUCED CARBON EMISSIONS"** and has approved for presentation at "**3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS- 2025)"** scheduled to be held on **10th – 11th May, 2025** at **Himachal Pradesh University, Shimla**, H. P., India in Hybrid mode.

We believe that your presentation will make a valuable contribution to the conference. Your Paper ID is **ICRTMS_183**

We request you to **fill the registration form,** if not done already, and mail your f**ull length paper in PDF format** latest by **25th April, 2025.**
Please feel free to contact us for any queries.
To register, please fill out the Google Form available at the link:
https://forms.gle/X1qh8EtQetFBoXLe9

Lodging Arrangement
The organizing committee of ICRTMS-2025 makes arrangements for the stay of participants in nearby guest houses and hotels. The participants are free to exercise their choice about their stay for which they have to immediately contact the concerned guest house or hotel. **The participants are requested to book their accommodation by the end of March, 2025 as in the months of May and June there is tourist season in Shimla.**

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Contact Details: **+91-8262858998**

Thank you for your contribution to the conference.

On behalf of organizing committee

Dr. Neetu Dhiman
Convener
ICRTMS- 2025
Contact-+91-7018451738
Conference Website: https://icrtms25.hgp.org.in

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10th-11th May, 2025

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This is to certify that **Mr. Deepak kumar , UG/PG Student, Delhi Technological University , Delhi** has presented a research paper entitled **Optimizing multi model transportation problem for reduce carbon emissions** in **3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS-2025)** organized by the **Himachal Ganita Parishad (HGP) at Himachal Pradesh University, Shimla** on **10th-11th May, 2025**.

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