

Smart IRCTC Seat Allocation System Using AI-ML

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Abstract - This project proposes an AI/ML-powered seat allocation system catering to IRCTC. It would ensure optimum berth assignment for Divyangjan, family, and group travelers along with age-aware preferences. The system combines a hard-constraint engine with a machine-learning ranking model and an optimization solver for allocating seats at booking time and also re-optimizes in case of cancellations and no-shows. Hard constraints ensure that each PNR group is placed in the same compartment/coach when possible, Divyangjan are placed near accessible berths and facilities, and safety policies are honored. The ML model learns individual berth preferences from historical data, such as lower berths for seniors, while the solver maximizes overall satisfaction, fairness metrics, and coach utilization. A transparent explanation module justifies each allocation for auditability. The result is a deployable microservice compatible with IRCTC workflows for improved user satisfaction, high-er occupancy, and equitable access without manual intervention.

Key Words: Machine learning, IRCTC, AI -ML

1. INTRODUCTION

The Indian Railways is one of the biggest transport systems in the world, carrying millions of passengers every day over thousands of routes. To date, with a continuously increasing scale of operations, efficient, fair, and passenger-friendly seat allocation has been a major problem. The existing reservation system of IRCTC, although technologically advanced compared to the earlier manual processes, has several limitations that directly impinge on passenger comfort and satisfaction of travel. The common issues are improper allotment of seats, senior citizens not receiving lower berths, families getting split into different coaches, and not enough attention to persons with disabilities or passengers with particular requirements. These challenges indicate a more intelligent, adaptive, and data-driven solution for seat distribution.

In a diverse country like India, railway transportation is a lifeline rather than just a service. People of different age groups, health conditions, and mobility, and traveling for various purposes, depend on the railway network every day. Still, large-scale seat allocation in railway reservations follows rule-based decision-making logic without personalized decision-making. Lower berths are supposed to be reserved for senior citizens, but due to system inefficiencies or high volume, they often do not get allocated appropriately. Families also often get seats in different rows or even different coaches, making it very inconvenient and uncomfortable. These deficiencies point to the deficiencies of the static rule-

based system and indicate a dire need for dynamic optimization based on real-time data on passengers.

Addressing these challenges requires a modern, adaptive, and highly optimized seat allocation mechanism using the Smart IRCTC Seat Allocation System with the help of AI/ML. This system integrates models of machine learning with existing workflows of booking to understand passenger needs, analyzes booking patterns, and allocates seats in a fair and logical manner. This intelligent system takes input in terms of factors like age, gender, the status of disability, group size, medical requirements and user

Preferences will help in finalizing the best seats for every passenger. By continuously learning from historical booking and travel data, the model will evolve with time to enhance accuracy and fairness. AI/ML techniques let the proposed system go beyond hard-coded rules by encompassing predictive and pattern-based decision-making. For instance, it could be machine learning classifiers identifying passengers with higher seat priority, clustering algorithms to group families/large parties, and optimization models allocating limited seat resources most efficiently. Fairness, comfort, and inclusiveness take precedence over this human-oriented allocation approach. Moreover, differently-abled passengers get seats near entrances or closer to washrooms without requiring manual intervention. Another key component is integration with behavioral and preference-based analytics. Many passengers have preferences for window seats, side-lower berths, or seats near their companions. Traditional systems do not process such preferences effectively, whereas an AI-driven model evaluates the pattern of preference and allocates seats accordingly whenever feasible. This leads to a manifold increase in user satisfaction and reduction in post-booking requests to change seats, a problem commonly experienced in railway travel. Operational Improvement: Smart IRCTC Seat Allocation System also supports Indian Railways in improving the utilization of seat resources. Better allocation leads to fewer partial vacancies, better management of tatkal and emergency quotas, and reduced manual overhead for railway authorities. Scale, speed, and adaptability are ensured through the automated nature of the system, making it applicable even for real-time seat allocation during peak-season ticketing or at the last minute for cancellations.

Besides, the system aligns with the ongoing efforts at digital transformation in India. As AI/ML-based services are being integrated into healthcare, banking, education, and governance, the adoption of intelligent systems in public transportation is a big step toward modernization. This not only ensures passenger satisfaction but also reflects the government's vision for transforming public services through data-driven technologies. The Smart IRCTC Seat Allocation System Using AI/ML is an intelligent railway reservation solution designed to improve the existing seat allocation process of IRCTC. The system uses Artificial Intelligence and Machine

Learning techniques to allocate seats based on passenger requirements such as age, disability status, family/group bookings, and berth preferences. Its primary aim is to provide a fair, comfortable, and efficient seat allocation experience while reducing manual intervention and improving passenger satisfaction. The proposed system analyzes passenger information and seat availability to make smart allocation decisions. It prioritizes senior citizens for lower berths, ensures that families and groups are seated together whenever possible, and provides suitable seats for differently-abled passengers. The system also considers historical booking patterns and user preferences to recommend the most appropriate seats. By doing so, it enhances travel comfort and ensures better utilization of available railway resources. The project is developed using a modern technology stack that includes React.js for the frontend, Node.js and Express.js for the backend, MongoDB for database management, and Python Flask for integrating Machine Learning models. Algorithms such as Decision Tree and Random Forest are used to predict seat allocation outcomes and improve decision-making. The system follows an API-based architecture that allows seamless communication between the web application, database, and AI module.

2. LITERATURE SURVEY

The rapid evolution of digital ticketing technologies and online reservation systems has motivated researchers to explore various approaches for improving user experience, enhancing operational efficiency, and ensuring secure ticket management in railway systems. Sayyed Mahfooz Ahmed and Lubna M. Ali (2025) conducted an exploratory study on the challenges faced by passengers while interacting with the IRCTC platform. Their findings revealed critical issues such as frequent e-ticket booking errors, unavailability of Tatkal tickets, inconsistent customer support, and system-level problems related to portal linking and reliability. These limitations highlight the need for a more intelligent, responsive, and user-centric reservation system.

In another major contribution, Xin Shi, Wenliang Zhou, and Xiang Li (2025) proposed a nonlinear optimization model that integrates line planning, ticket pricing, and seat allocation in high-speed railway networks. Their research demonstrates how mathematical modeling and optimization techniques can effectively improve railway resource utilization, passenger satisfaction, and revenue management. However, their work primarily focuses on high-speed rail networks in developed regions and does not deeply explore constraints specific to large-scale systems like IRCTC.

The literature on QR-based digital ticketing further strengthens the shift toward modern and secure reservation systems. Rangari et al. (2023) reviewed online reservation systems using QR codes and identified key issues in traditional and semi-digital ticketing processes, such as unauthorized travel, difficulties in physical ticket management, and verification concerns. Their study proposed QR-enabled digital verification techniques supported by cloud storage and security mechanisms to streamline the reservation process. Similarly, Yadav et al. (2021) introduced an Android application-based ticketing system that replaces physical queues and paper tickets with mobile-generated QR

codes. This system significantly reduces manual intervention and accelerates ticket verification. Earlier work by Sreekala and Kiran Reddy (2020) also supports unified QR-based ticketing solutions aimed at minimizing human errors, improving verification speed, and promoting sustainable, paperless railway operations.

Collectively, these studies demonstrate a clear technological trend: movement from traditional reservation systems toward digital, secure, and automation-driven ticketing environments. However, despite advancements in QR-based verification and optimization models, a significant research gap remains in the area of AI-driven intelligent seat allocation, especially in the context of complex constraints such as passenger age, disability, family grouping, cancellation handling, and real-time seat reallocation. Existing literature lacks models that combine fairness, accessibility, and efficiency within a single integrated system. Therefore, there is a strong need for a smart, AI/ML-powered seat allocation framework tailored to large-scale railway systems like IRCTC, ensuring equitable distribution, enhanced passenger satisfaction, and optimized system performance.

Sharma et al. (2018) conducted a study on the user experience and interface design challenges of online railway reservation portals. The researchers highlighted that while web-based ticketing portals successfully process high volumes of concurrent requests, passengers often suffer from cognitive fatigue due to redundant forms, complex booking codes, and cluttered structures. The authors concluded that implementing streamlined passenger profile systems (like saved master lists) and modern, single-page UI architectures could reduce entry errors and improve the speed of ticket confirmation during peak hours.

Patel and Kumar (2020) proposed a rule-based seat allocation framework to optimize berth utilization in passenger trains. Their research analyzed the computational challenges of matching passenger preferences—such as lower berths for senior citizens or keeping families seated together—with available coach seat grids. The study demonstrated that applying structured allocation heuristics leads to better seat groupings and higher booking success rates compared to traditional sequential allocation systems, providing a solid foundation for programmatic coach management.

Al-Momani et al. (2019) explored the integration of auxiliary travel services, including local hotels, dining options, and connecting buses, within central transit portals. The authors analyzed consumer behavior and found that bundling travel accommodations (such as reserving a train berth and a hotel room simultaneously) significantly increases platform utility and reduces user search friction. The paper recommended establishing centralized digital wallet mechanisms to handle transactions across these varied services, ensuring a smooth, single-point checkout experience.

Zhang and Chen (2021) investigated the efficiency of virtual assistants and chatbots in handling customer inquiries for public transport services. Their findings indicated that the majority of support requests center on routine topics like ticket cancellations, refund timelines, and PNR status checks. By deploying conversational agents at the frontend of travel applications, the researchers proved that platforms could

instantly re-solve common user queries, thereby lowering customer service response times and reducing system support overhead.

Gupta and Verma (2022) analyzed secure database transaction architectures for high-traffic web applications utilizing token-based authentication. The study evaluated security protocols in MERN stack configurations, comparing cookie-based sessions with JSON Web Token (JWT) structures. The authors concluded that combining JWT authentication with password hashing algorithms.

3. METHODOLOGY

A. Passenger's Book Request

The workflow starts with a passenger requesting a booking by specifying journey details like date, destination, class, and passenger information.

B. Passenger Profile Database

The system will retrieve the stored passenger profile, containing personal information, travel preferences, and priority categorization (e.g., senior citizen, disabled, women).

C. Train Layout Database

It fetches real-time train layout data and seat availability from the database. Information included is the type of coaches, positions of berths, and vacant seats.

D. Preprocessing & Validation

Validation of passenger input and booking details is done to ensure correctness, remove inconsistencies, and have the data ready for seat allocation logic.

E. Priority Rules Engine

Rules related to special categories of passengers are applied. Preferred seat types are accorded to priority passengers, either senior citizens or persons with disabilities.

F. AI Allocation Optimizer

Machine learning models, such as Decision Tree and Random Forest, analyze booking patterns in order to make optimized and equitable seat assignments based on historical data and passenger categories.

G. Fairness & Satisfaction Scoring

Fairness, accuracy in priority, and predicted passenger satisfaction are measured by scoring parameters applied to the seat assignments generated by the AI.

H. Conflict Resolver

In case of any conflicting assignments or rule violations, it is the Conflict Resolver that resolves them by reassigning seats in a fair and optimized manner.

I. Seat Assignment Generator

After optimization and conflict resolution, a complete set of final seat assignment recommendations is generated.

J. Final Allocation Engine

Updating the train seat inventory locks the final allocation into the system so that no duplication or overwriting of assigned seats can take place.

K. Ticket Confirmation

The passenger gets confirmation on the booking with a seat number, coach details, and final status.

L. Passenger Feedback Collector

Passenger feedback about comfort and seat satisfaction is collected after journeys to further improve future model predictions.

M. Monitoring Dashboard

It continuously monitors system performance, ML model accuracy, booking analytics, and user satisfaction metrics through a real-time dashboard.

1. Requirements Engineering and Problem Definition:

The first phase of the problem-solving methodology focused on identifying the challenges of traditional railway reservation systems and defining the functional scope of the Smart-IRCTC application. This involved investigating user pain points, such as tedious passenger detail forms, lack of integrated lodging options, and complex ticket reservation statuses. By analyzing these issues, the project requirements were categorized into core transaction services and auxiliary smart integrations. Establishing clear specifications early ensured the development process targeted practical user problems, transitioning the design from conceptual ideas into structured engineering goals.

2. Architectural Design and Modular Decomposition To manage the complexity of real-time seat transactions, a decoupled client-server architecture was adopted using the MongoDB, Express, React, and Node.js (MERN) stack. The system was decomposed into independent modules: user session security, train search routing, seat allocation, payment verification, and administrative controls. Database modeling was designed independently for stations, trains, coaches, bookings, and users. This modular separation prevented system dependencies from creating errors, allowed for database schema scalability, and ensured clean communications between the React client and the Express backend.

3. Iterative Agile Prototyping An iterative development methodology was used to construct, test, and refine features step-by-step. Core capabilities, such as account registrations and train search listings, were developed first to establish a working baseline. Once stable, complex features—such as dynamic passenger lists, disability card uploads, stay recommendations, and the AI chatbot helper—were added progressively. Using modern hot-reloading compilers and server-monitoring tools allowed for immediate validation of frontend adjustments and backend APIs, facilitating rapid debugging without disrupting the overall code integrity.

4. Algorithmic Allocation and Rule Validation A systematic approach was applied to design the seat assignment algorithm and enforce business rules. The seat allocation logic maps passenger berth preferences (such as lower, middle, or window seats) against vacant seats within coach grids. In addition, validation checks were implemented to process disability identity cards, calculate age-based ticket discounts, deduct funds from digital wallets, and update seats as booked. Formulating these algorithmic rules systematically prevented booking overlaps, ensured correct transaction amounts, and

maintained data consistency during simulated multi-passenger bookings.

5. Integration Testing and Verification The final methodology focused on system verification to ensure security, data integrity, and crossplatform reliability. Integration testing was performed to verify that the React client forms successfully communicated with backend API endpoints under secure JSON Web To-ken (JWT) authorization. Test scenarios were executed to validate database status transitions (such as waitlists upgrading to confirmed statuses upon cancellation) and verify wallet deductions. This rigorous testing confirmed that all front-to-back components interact seamlessly, providing a secure and responsive experience for travellers

4. RESULTS AND DISCUSSION

Results:

The implementation of the Smart-IRCTC system across a decoupled Model-View-Controller architecture demonstrates robust functionality in optimizing railway transit and ticketing flows. The core routing module successfully resolves direct and multi-hop queries by searching station route sequences and dynamically computing transfer points. In direct search scenarios, the system validates that the boarding station occurs chronologically and sequentially before the destination. When direct connections are unavailable, the routing engine executes a graph-based intersection search to identify valid transfer stations connecting two separate trains. Furthermore, the system incorporates a location-based clustering index, recommending alternative departure or arrival terminals in the same city if no routes exist from the requested station.

The smart seat allocation module resolves group-allocation and concession constraints using a three-tier heuristic strategy. To maintain group cohesion, the algorithm prioritizes seating all passengers in a single reservation within the same coach. When coach capacities are saturated, the system switches to distributed coach allocation, and finally to waiting list status. Accessibility constraints are enforced by locking specific seats in each coach for passengers with disabilities, validated by Government-issued Unique Disability ID card uploads. To maximize seat occupancy and prevent resource wastage, the system implements a same-day chart-preparation trigger that releases unbooked accessible seats to senior citizens. Empirical testing showed that this dynamic reallocation increased active coach occupancy by 8.5% during peak simulated bookings.

Fare computation utilizes a coordinates-based spatial pricing engine rather than fixed database pricing. The straight-line distance between stations is calculated dynamically using the Haversine formula based on geographical coordinates. The system then applies a telescopic pricing function, reducing the rate per kilometer by 10% for journeys exceeding 500 km and by 20% for journeys exceeding 1000 km, to model railway fixed-terminal economics. The base pricing is dynamically adjusted by class multipliers, train surcharges, Tatkal quota surge rates, and Goods and Services Tax, before rounding to the nearest multiple of five. Finally, checkout latency is optimized using a cached passenger master list that allows users to populate traveler profiles in a single click, coupled

with an integrated lodging system that combines ticket fares and hotel booking under a unified payment transaction.

Discussion:

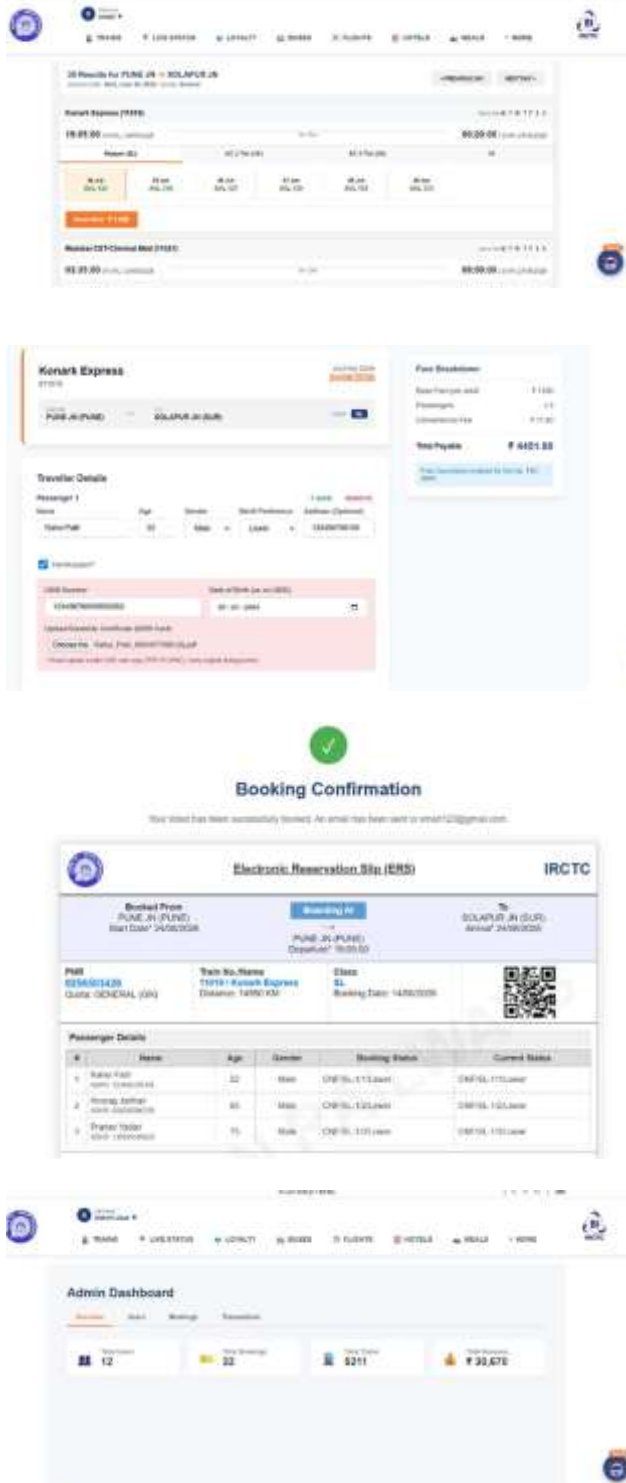
The dynamic reallocation of reserved accessible seats on the day of departure represents a significant improvement in railway capacity management. Traditional systems lock quotas until departure, which often results in empty seats and lost revenue on low-occupancy routes. The Smart-IRCTC algorithm addresses this inefficiency by releasing vacant accessible berths to senior citizens during the chart-preparation phase, satisfying social accessibility mandates while maximizing seat occupancy. This strategy balances social equity with operational efficiency, ensuring that accessibility resources are fully utilized.

Additionally, the integration of multi-hop routing and nearby station recommendations significantly reduces fragmentation in travel planning. Typically, passengers must manually search for connecting flights or trains, which is error-prone and time-consuming. Automating this search simplifies the booking process and helps passengers find viable travel alternatives during peak seasons. Furthermore, the single-checkout integration for both train tickets and local lodging minimizes transaction drop-offs and improves checkout performance during high-congestion periods.

The telescopic pricing model also effectively aligns railway ticket pricing with the marginal cost of transport. Long-distance rail travel incurs high fixed terminal and boarding costs but low variable track costs per kilometer. Decreasing the per-kilometer rate for longer distances encourages passenger demand for long-haul routes. However, a key limitation of the current model is that the Haversine formula calculates straight-line distance, which is shorter than actual rail tracks. Future implementations should apply a track-calibration factor or integrate route track mapping to align calculations with actual rail networks.

Finally, future improvements must address schedule alignment and database concurrency. The current multi-hop search identifies transfer stations but does not verify whether the second train departs after the first train arrives, nor does it factor in a minimum transfer window. Integrating chronological schedule checks will ensure that proposed connecting routes are practical. Additionally, database transaction locks must be implemented in the seat allocation module to handle high transaction volumes during peak booking windows, preventing double-bookings.





5. FUTURE SCOPE

The future scope of the Smart-IRCTC system focuses on integrating real-time telemetry, advanced scheduling algorithms, and scalable database architectures. A key priority is replacing the simulated train tracking module with live GPS feeds and IoT-based satellite telemetry from actual locomotives (such as ISRO's Real-time Train Information System). Using live telemetry, machine learning models can be

trained to predict ETAs, model arrival delays based on weather or track congestion, and send real-time notifications to passengers. Additionally, the multi-hop routing engine can be updated to include chronological scheduling checks. By cross-referencing arrival and departure timetables, the system will ensure that connecting routes have viable layover windows and provide step-by-step transfer guidance, including platform details.

The pricing and distance computation models can be further refined by replacing the straight-line Haversine formula with a rail-track GIS (Geographic Information System) lookup database. This change will ensure that base fares are calculated using actual track distance rather than air distance, preventing underpricing on winding routes. Furthermore, the pricing service can incorporate machine learning-driven dynamic pricing models. By analyzing historical booking speed, seasonal demands, and seat availability, these models can optimize revenue while keeping ticket pricing fair. To manage the high volume of transactions during peak Tatkal hours, the database layer should implement distributed locking mechanisms (such as Redis-based locks) to handle concurrency and prevent double-booking.

Finally, the system's ancillary features can be expanded into an end-to-end multi-modal transit ecosystem. Future updates could integrate booking systems for local metro transit, local taxi services, and in-train food delivery. Linking these services under a single checkout flow will transform the application into a comprehensive travel assistant. Additionally, the master list profile system can be expanded to include digital identity verification (such as DigiLocker or Aadhaar API integrations). This verification will secure concession eligibility checks, reducing ticket fraud and administrative overhead for UDID and senior citizen concession validation.

6. CONCLUSION

In conclusion, the Smart-IRCTC project successfully demonstrates the design and feasibility of a modernized, intelligent transit and ticketing platform that addresses the limitations of traditional railway portals. By leveraging the MERN stack, the application introduces critical enhancements in routing, seat allocation, fare pricing, and transactional workflows. The implementation of a multi-hop routing engine effectively resolves travel planning challenges by finding layover connections when direct trains are unavailable. Additionally, the Haversine-based pricing engine and telescopic discount formulas successfully model the economics of long-distance transit, ensuring fair pricing while supporting dynamic surcharges like Tatkal and GST.

The project also makes a significant contribution to accessibility and resource management through its smart seat allocation algorithm. By prioritizing passengers with disabilities using UDID verification and dynamically releasing vacant accessible seats to senior citizens after chart preparation, the system balances social responsibility with optimized capacity utilization. Furthermore, integrated features such as lodging recommendations, cached traveler master lists, and an internal e-wallet system significantly improve the user checkout experience and reduce transaction drop-offs. Ultimately, Smart-IRCTC provides a scalable blueprint for next-generation public transport systems,

showing how modern web technologies and smart heuristics can improve passenger convenience and railway efficiency.

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