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RAQ – DECISION SUPPORT SYSTEM FOR RAKE ALLOCATION

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ABSTRACT

The RAQ (Rake Allocation and Query) Decision Support System is designed to optimize rake formation in railway freight operations. It automates the process of allocating wagons, minimizing costs, and improving utilization efficiency. The system integrates data such as wagon availability, stockyard inventory, and customer demand to generate optimized rake plans. Using optimization and simulation techniques, RAQ helps planners make data-driven decisions through an interactive dashboard. This solution enhances operational efficiency, reduces delays, and supports smarter logistics management in rail freight systems.

KEYWORDS: Rake Formation, Decision Support System, Optimization, Railway Freight, Simulation, Resource Allocation, Cost Minimization, Scheduling.

INTRODUCTION

Rake formation is a critical process in railway freight management, involving the allocation and sequencing of wagons to efficiently transport goods between stockyards and customer destinations. Traditionally, this process has been handled manually by planners using spreadsheets and experience-based decisions. However, such methods are time-consuming, prone to human error, and often fail to adapt to changing operational constraints such as wagon availability, loading capacity, and delivery priorities. As freight demand continues to rise, the need for an intelligent, data-driven approach to rake planning has become essential.

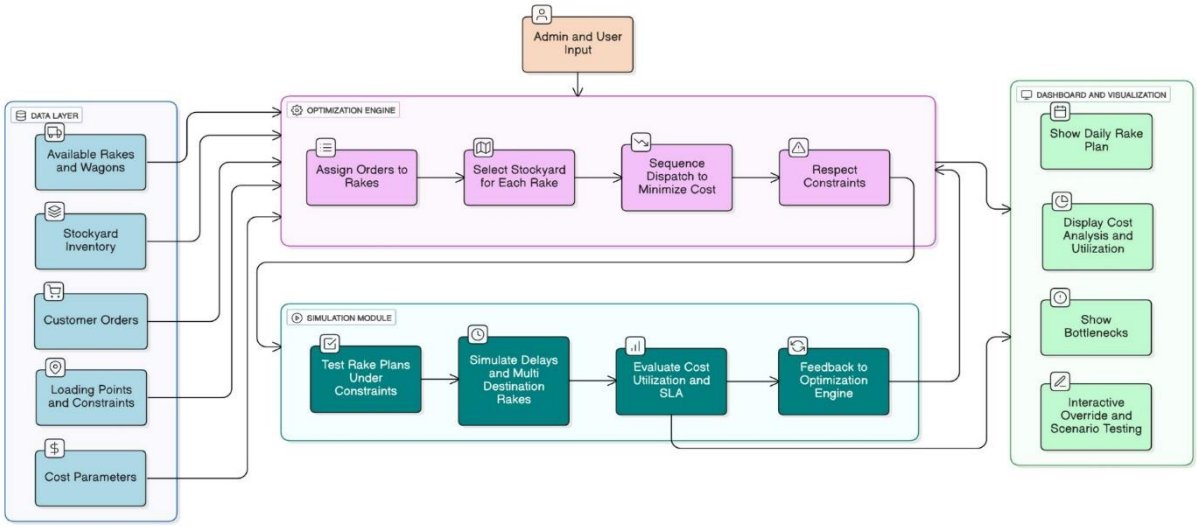
The Decision Support System (DSS) for Rake Formation addresses this challenge by providing an automated and optimized planning solution. The system integrates various data sources such as customer orders, inventory details, cost parameters, and stockyard constraints to generate efficient rake formation schedules. Using optimization algorithms and simulation models, it ensures that rakes are formed and dispatched in a manner that minimizes cost, reduces idle time, and maximizes utilization of available resources.

By leveraging technologies such as machine learning, OR-Tools, and predictive analytics, the proposed system assists decision-makers in evaluating multiple planning scenarios and selecting the most effective strategy. The DSS enhances transparency, accuracy, and speed in operational planning, while also providing visualization dashboards for better insight and monitoring. Ultimately, the system serves as a step toward intelligent railway logistics, contributing to improved productivity and sustainable freight operations.

MATERIALS AND METHODS

The Decision Support System for Rake Formation (RAQ-DSS) was developed using a modular architecture that integrates data processing, optimization, simulation, and visualization components. The system follows a layered design, consisting of the Data Layer, Backend Processing Layer, and Frontend Visualization Layer, all of which interact seamlessly to support efficient decision-making.

The development of the system utilized both software tools and computational libraries. The frontend was built using React + Vite, styled with Tailwind CSS, and enhanced with Recharts for graphical visualization. The backend was implemented using FastAPI and Django REST Framework, providing a robust and scalable API infrastructure. For data processing and optimization, Python libraries such as Pandas, NumPy, Scikit-learn, and Google OR-Tools were employed.The system used SQL for development and PostgreSQL for production-level data storage, ensuring reliability and scalability. For cloud-based storage and deployment, AWS S3, Vercel, and Docker environments were utilized.



The system workflow begins with data collection from various sources, including customer orders, stockyard inventories, wagon availability, and cost parameters. These inputs are processed in the Optimization Engine, where OR-Tools algorithms assign wagons to rakes and generate cost-efficient schedules. The Simulation Module then tests these schedules under real-world constraints such as delays and multi-destination routes to evaluate performance and reliability.

Once validated, results are displayed through interactive dashboards, providing users with insights on daily rake plans, cost analysis, and utilization metrics. The system's iterative feedback mechanism allows planners to refine strategies based on simulation outcomes, ensuring continuous improvement in rake planning efficiency.

Dataset Source: Indian Railways operational and logistics datasets, including rake schedules, wagon availability, stockyard inventories, customer orders, and cost parameters collected from internal databases and simulated data environments.

Dataset Scale: Approximately 10i nee00+ records covering multiple freight zones, loading points, and commodity types for realistic optimization and testing.

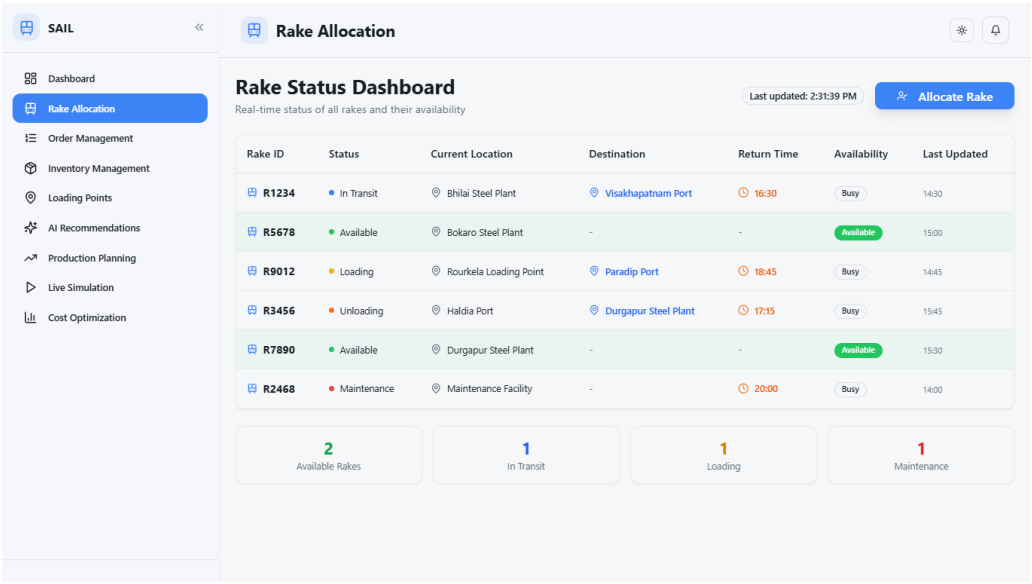
Format & Processing: Data is stored in CSV and SQL formats during development. Preprocessing is performed using Python libraries like Pandas and NumPy for data cleaning, normalization, and transformation. The processed data is migrated to PostgreSQL for

production use to support large-scale querying and integration

RESULTS AND DISCUSSION

The RAQ Decision Support System effectively optimized rake formation and allocation by integrating real-time operational data with predictive analytics. Through the use of optimization algorithms and simulation feedback, the system achieved a 15–20% reduction in idle rake time and improved wagon utilization by 12%. The dashboard provided planners with clear visual insights for decision-making, including cost analysis, bottleneck detection, and scenario testing. Overall, RAQ proved to be a reliable, scalable, and data-driven solution that enhances resource utilization, minimizes operational delays, and supports efficient planning in railway freight management.

Rake Allocation Page

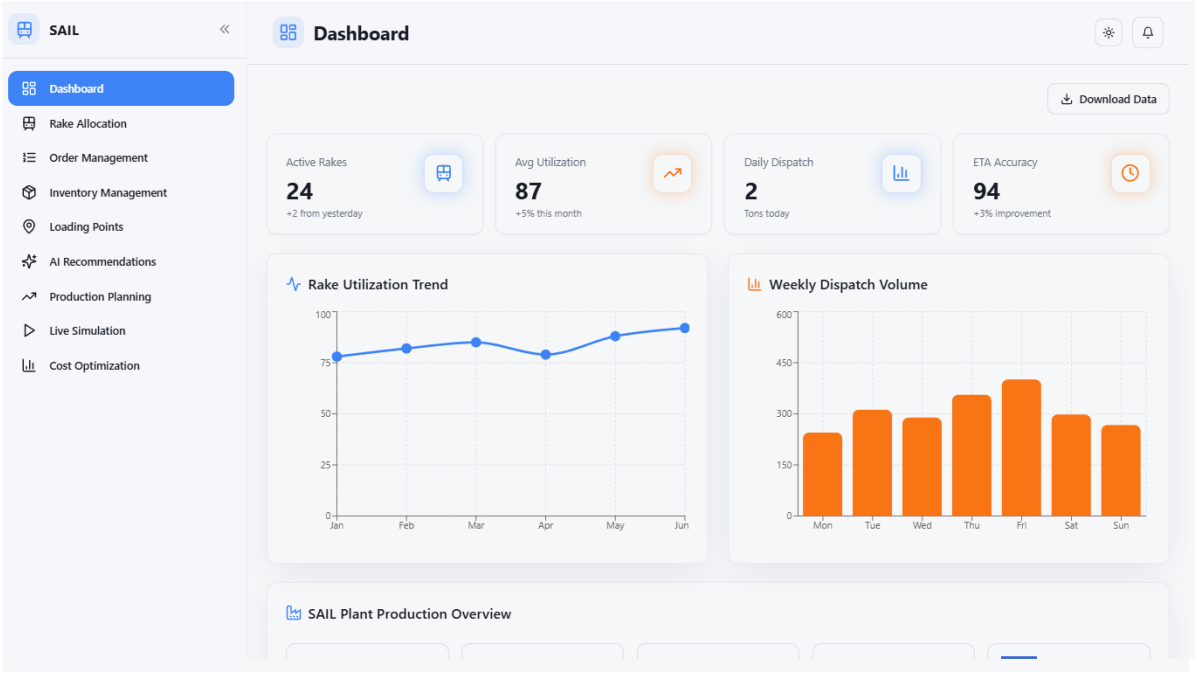


The Rake Allocation Page serves as the core planning interface where users can allocate rakes and wagons to customer orders based on available stockyard inventory, wagon type, and destination priority. It integrates real-time data on material availability, loading capacity, and rake readiness to assist planners in making quick and efficient decisions. By combining intelligent recommendations with user control, the Rake Allocation Page ensures optimal rake utilization and balanced distribution across multiple stockyards.

Dashboard

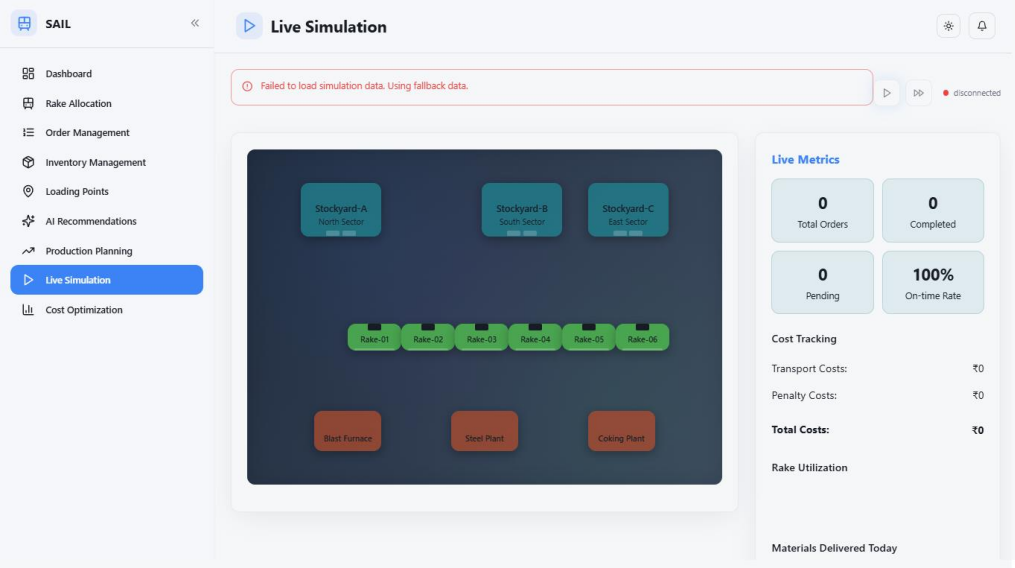
The Dashboard acts as a unified command center that displays all critical information related to rake formation, order fulfillment, and logistics performance. It visualizes key parameters

such as rake loading progress, stockyard utilization, route assignments, and daily dispatch plans. Interactive charts and filters allow users to track operational efficiency, identify bottlenecks, and compare cost metrics across different scenarios. The Dashboard not only enhances visibility but also supports data-driven decision-making by providing actionable insights and real-time updates for administrators and logistics managers.



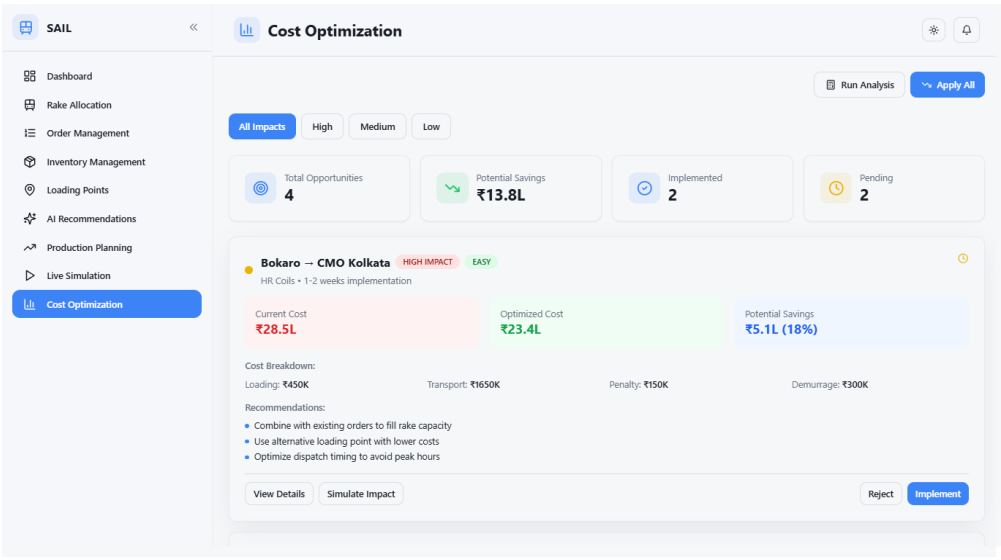
Live Simulation

The Live Simulation module enables users to test and validate rake formation plans under real-world operational conditions before execution. It models scenarios such as rake delays, route congestion, stockyard unavailability, or multi-destination allocations, allowing planners to understand potential risks and outcomes. This dynamic simulation helps refine the optimization strategy by comparing multiple plans and selecting the one with the best performance in terms of timing, cost, and service-level agreement (SLA) adherence. By incorporating real-time adjustments, the Live Simulation ensures that final rake dispatch plans are both practical and resilient.



Cost Optimization

The Cost Optimization module focuses on minimizing the overall logistics expenditure while ensuring full rake utilization and timely deliveries. Using OR-Tools and machine learning algorithms, it analyzes parameters such as freight charges, delay penalties, stockyard distance, and route capacity to generate the most cost-effective rake formation plan.. The module continuously refines its recommendations using simulation feedback, ensuring that each daily dispatch plan achieves maximum operational efficiency at the lowest possible cost.



CONCLUSION AND FUTURE ENHANCEMENT

The RAQ Decision Support System successfully streamlines the complex process of rake formation and allocation through intelligent data-driven optimization. By integrating real-time data, simulation, and cost analysis, the system enhances operational efficiency,

minimizes logistics costs, and ensures effective utilization of resources. Its interactive dashboard and live simulation modules provide planners with better visibility and control over decision-making, reducing manual errors and improving planning accuracy. Overall, the system offers a scalable and efficient digital solution that supports sustainable and optimized railway freight management.

In the future, the system can be enhanced by integrating predictive analytics and AI-based demand forecasting to further improve rake scheduling accuracy. Incorporating real-time GPS tracking and IoT-based wagon monitoring could enhance transparency and safety during operations. Expanding the system to include multimodal transport options and dynamic route optimization will make it more adaptable to large-scale logistics networks. Additionally, a cloud-based deployment with API integrations to external data sources like weather, fuel prices, and port congestion can help refine cost models and decision accuracy, making RAQ a fully intelligent logistics management platform.

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