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A RULE-BASED ANALYTICS FRAMEWORK FOR DELIVERY DELAY ANALYSIS AND SLA OPTIMIZATION IN QUICK COMMERCE

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ABSTRACT
Quick commerce platforms operate under strict service level agreements (SLAs), where even small delivery delays can significantly impact customer satisfaction. Managing such delays is challenging due to high order volumes, limited delivery personnel, demand fluctuations, and operational bottlenecks across different zones. This paper presents a rule-based analytics framework for analysing delivery performance and optimizing SLA compliance in quick commerce operations. The proposed system uses historical delivery data stored in a relational database and applies descriptive and diagnostic analytics to identify delay patterns and root causes. The framework includes multiple analytical modules such as overview analysis, delay root cause identification, micro-zone performance evaluation, rider efficiency analysis, warehouse picking analysis, and a risk-based simulation module. A workload-based what-if simulation approach is employed to evaluate the impact of operational changes such as rider addition and order load reduction on SLA performance. The system is implemented using Python for analytics, MySQL for data storage, and Streamlit for interactive visualization. Experimental results from a real-world city-level dataset demonstrate that the proposed framework effectively identifies operational bottlenecks and provides actionable insights for improving delivery efficiency and SLA compliance.

Keywords:
Quick Commerce, Delivery Analytics, SLA Optimization, Rule-Based Analysis, Operational Simulation, Last-Mile Delivery

1. INTRODUCTION

Quick commerce has emerged as a critical segment of the retail and logistics industry, offering ultra-fast delivery of essential goods within short time windows. Customers increasingly expect deliveries to be completed within strict service level agreements (SLAs), often ranging from 10 to 45 minutes. As a result, delivery performance has become a key competitive factor for quick commerce platforms. However, maintaining consistent SLA compliance is challenging due to fluctuating demand, traffic conditions, limited delivery personnel, and operational constraints across different geographic zones.

Delivery delays in quick commerce are not caused by a single factor but are the result of multiple interconnected processes, including warehouse picking, order dispatch, rider availability, and last-mile delivery. Traditional monitoring approaches often focus only on overall delivery time, making it difficult to identify the exact sources of delay and implement targeted improvements. There is a growing need for data-driven analytical frameworks that can provide both descriptive insights into delivery performance and diagnostic insights into the underlying causes of delays.

This paper proposes a rule-based analytics framework for analyzing delivery delays and optimizing SLA performance in quick commerce operations. The framework leverages historical delivery data to perform multi-level analysis, including overview monitoring, delay root cause identification, micro-zone performance evaluation, rider efficiency analysis, warehouse picking assessment, and risk-based simulation. By combining

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analytical insights with what-if simulation, the proposed approach supports informed decision-making for improving operational efficiency and SLA compliance.

2. RELATED WORK

Several studies have examined delivery performance and delay management in last-mile logistics and e-commerce systems. Previous research has focused on improving delivery efficiency through routing optimization, demand forecasting, and vehicle allocation strategies. Many works employ machine learning and optimization techniques to predict delivery times and minimize transportation costs under varying demand conditions.

Recent studies have also explored the use of data analytics for monitoring service level agreements (SLAs) in urban delivery networks. These approaches typically analyze historical delivery data to identify performance trends and evaluate the impact of traffic conditions, order volume, and resource availability. However, such methods often emphasize prediction accuracy rather than operational interpretability. In the context of quick commerce, limited research has addressed explainable, rule-based analytical frameworks that integrate descriptive analysis, diagnostic insights, and operational simulation within a unified system. Existing solutions rarely provide decision-makers with interactive tools to evaluate what-if scenarios such as rider allocation changes or order load variations at a micro-zone level.

The present work differs from existing studies by proposing a modular, rule-based analytics framework that combines delay root cause analysis, micro-zone performance evaluation, rider efficiency assessment, warehouse picking analysis, and workload-based SLA simulation. The focus of this approach is not prediction but actionable, transparent insights that support operational decision-making in quick commerce delivery systems.

3. METHODOLOGY

The methodology adopted in this study is based on rule-based analytical processing of historical delivery data to evaluate performance and identify operational bottlenecks in quick commerce systems. The approach consists of sequential steps including data preparation, SLA evaluation, delay decomposition, performance analysis, risk assessment, and simulation-based optimization.

Initially, delivery-related data is extracted from a MySQL database and pre-processed to ensure consistency and accuracy. Timestamp fields corresponding to different stages of the delivery lifecycle, such as order placement, warehouse picking, dispatch, and final delivery, are converted into standardized datetime formats. Delivery duration and intermediate delay components are computed using time difference calculations.

SLA compliance is evaluated by comparing the actual delivery time of each order against predefined SLA thresholds. Orders delivered within the specified SLA time are classified as on time, while those exceeding the threshold are marked as delayed. This rule-based classification enables clear and transparent identification of SLA breaches. To identify delay root causes, the total delivery time is decomposed into multiple operational stages, including warehouse picking time, dispatch delay, and last-mile delivery time. The contribution of each stage to overall delay is analysed to determine dominant bottlenecks. Performance analysis is further extended to micro-zone and rider levels to capture spatial and human resource variations in delivery efficiency.

4. SYSTEM ARCHITECTURE

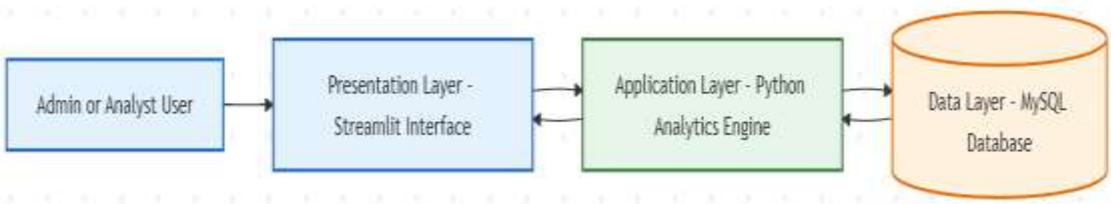

Figure 1: Proposed System Architecture

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The proposed system follows a modular, layered architecture designed to support scalable data analysis and interactive visualization for quick commerce delivery operations. The architecture consists of three primary layers: data storage, analytics processing, and visualization.

At the data storage layer, delivery-related data is maintained in a relational database using MySQL. The database stores structured information related to orders, delivery events, riders, and geographic zones. These tables collectively capture order timestamps, delivery stages, rider assignments, and zone-level attributes required for detailed performance analysis.

The analytics processing layer is implemented using Python and its data analysis libraries. This layer is responsible for data ingestion, preprocessing, timestamp conversion, and calculation of key performance metrics such as delivery duration, SLA compliance, delay components, and rider workload. Rule-based logic is applied to classify delivery status, identify delay sources, and assess operational risk. Additionally, a workload-based simulation mechanism is integrated to evaluate the impact of operational changes on SLA performance.

The visualization layer is developed using the Streamlit framework, which provides an interactive dashboard for users to explore analytical insights. The dashboard presents key metrics, charts, and zone-level comparisons across multiple analytical modules. User inputs such as zone selection, rider adjustments, and order reduction parameters are supported to enable real-time what-if simulation and decision support.

A risk assessment mechanism is incorporated using predefined thresholds to classify zones and operational conditions into low, medium, and high-risk categories based on SLA compliance and delay frequency. Additionally, a simulation-based optimization approach is employed to evaluate potential improvement strategies. In this simulation, rider availability and order volume are adjusted, and SLA performance is recalculated using workload-based scaling logic. This what-if analysis enables the evaluation of operational changes without real-world deployment costs.

5. RESULTS AND DISCUSSION

The analytical results provide valuable insights into delivery performance and operational bottlenecks within the quick commerce system. The overview analysis indicates that overall SLA compliance varies significantly across zones and time periods, with peak hours and night-time deliveries exhibiting higher average delivery times compared to non-peak conditions. This highlights the impact of demand surges and limited rider availability on delivery efficiency.

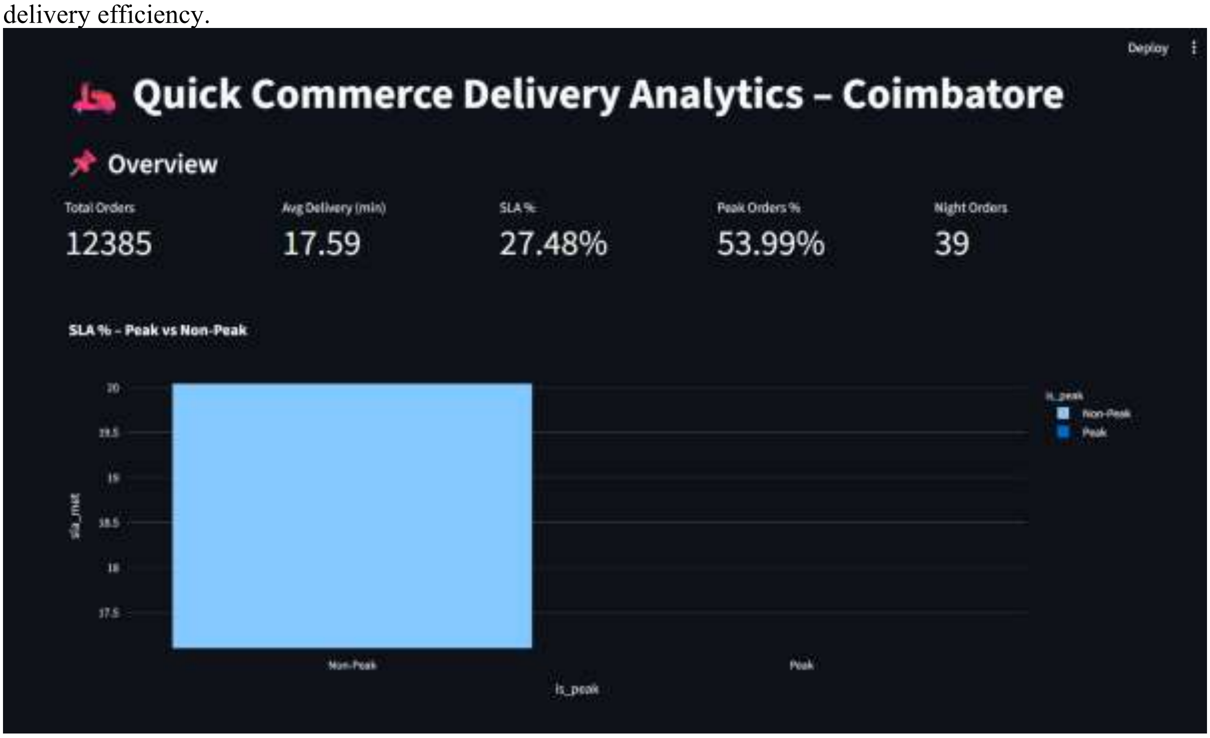

Figure 2: Overall SLA Compliance Analysis

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The delay root cause analysis reveals that delivery delays are influenced by a combination of warehouse picking time, dispatch delays, and last-mile delivery duration. In several cases, warehouse picking contributed a notable portion of the total delivery time, indicating that delays are not limited to last-mile operations alone. This emphasizes the importance of optimizing internal fulfilment processes alongside delivery routing. Micro-zone performance evaluation shows clear spatial variation in SLA compliance across different areas within the city. Certain micro-zones consistently demonstrate lower SLA percentages and higher average delivery times, indicating localized congestion and operational constraints. Such insights enable targeted interventions rather than uniform city-wide strategies.

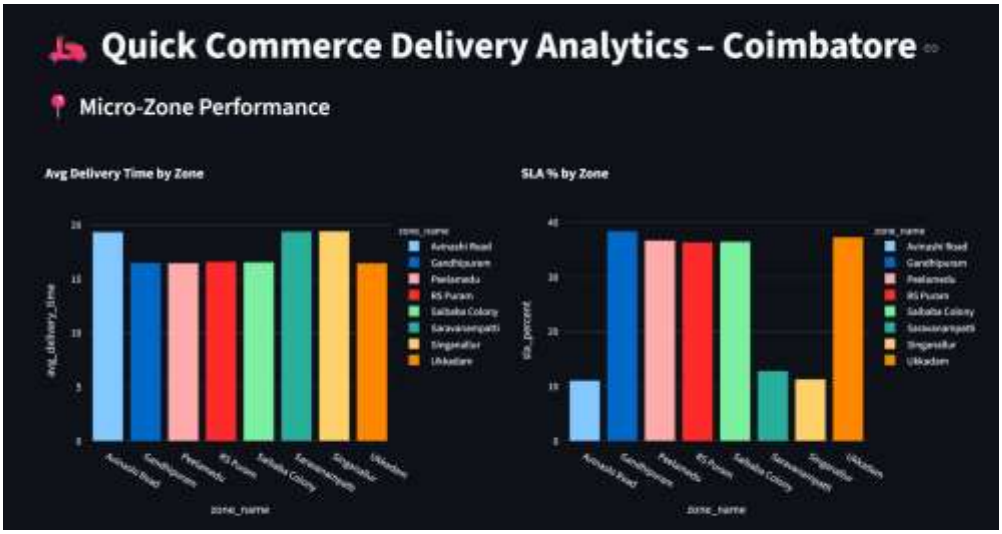

Figure 3: Micro-Zone Level SLA Performance Comparison

Rider efficiency analysis highlights variability in performance among delivery personnel. While some riders maintain high SLA compliance with lower average delivery times, others experience higher delay rates, often due to increased workload or zone-specific challenges. These findings support the need for balanced rider allocation and performance monitoring.

The risk and simulation module demonstrates the effectiveness of workload-based optimization strategies. Simulation results show that increasing rider availability and reducing order load in high-risk zones leads to a significant improvement in SLA compliance. The optimized SLA percentages obtained through simulation indicate that operational adjustments can substantially enhance delivery performance without additional infrastructure investment.

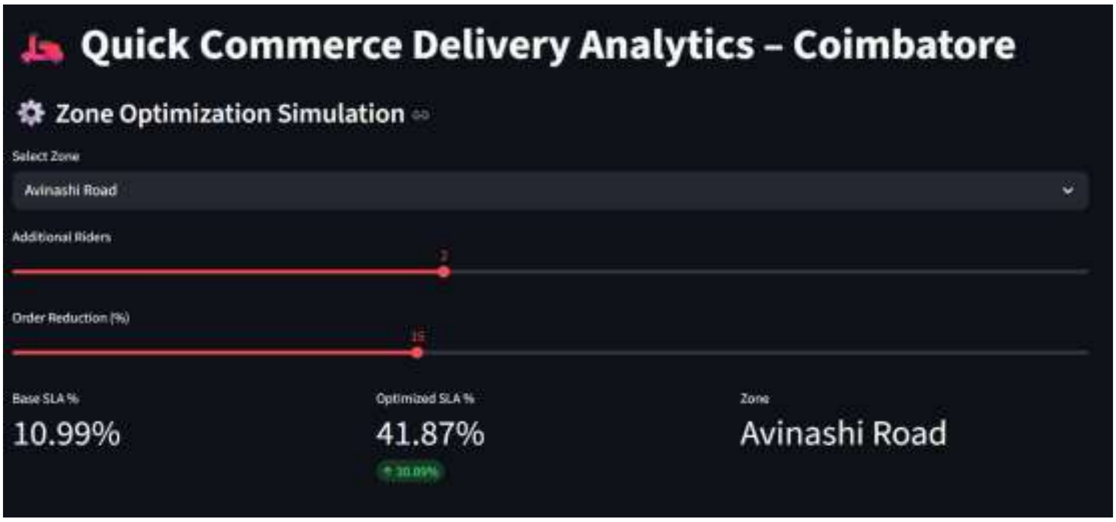

Figure 4: SLA Performance Under Workload-Based Simulation

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6. CONCLUSION AND FUTURE SCOPE

This paper presented a rule-based analytics framework for analysing delivery delays and optimizing SLA performance in quick commerce operations. By leveraging historical delivery data, the proposed system provides descriptive and diagnostic insights into delivery performance across multiple dimensions, including micro-zone efficiency, rider performance, warehouse picking operations, and operational risk. The modular design of the framework enables clear identification of delivery bottlenecks and supports data-driven decision-making.

The inclusion of a simulation-based optimization module demonstrates the practical value of analytical insights in evaluating improvement strategies. By adjusting rider availability and order load parameters, the system enables what-if analysis to estimate SLA improvements without real-world implementation costs. Experimental observations indicate that such workload-based optimization approaches can significantly enhance SLA compliance in high-risk zones.

As future work, the framework can be extended by incorporating predictive models for delivery time estimation, real-time traffic and weather data integration, and automated rider allocation strategies. Additionally, deploying the system with real-time streaming data and expanding analysis to multi-city scenarios would further enhance its applicability and operational impact.

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