DESIGN AND SIMULATION PLANNING OF AN AI AND WEB-GIS INTEGRATED SYSTEM FOR REAL-TIME LOGISTICS ROUTE OPTIMIZATION

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Abstract. The rapid development of digital technologies has significantly transformed logistics and transportation systems worldwide. Real-time monitoring technologies enable organizations to track, analyze, and optimize logistics operations continuously. In Uzbekistan, the modernization of transport and logistics infrastructure requires the implementation of advanced monitoring systems capable of providing accurate and timely information for decision-making. This study proposes a conceptual framework for a real-time monitoring system for transport and logistics operations. The framework integrates GPS technologies, Internet of Things (IoT) sensors, cloud computing, and data analytics tools to improve operational efficiency, reduce transportation costs, and enhance supply chain visibility. The proposed model offers a comprehensive approach for monitoring transportation processes and supporting strategic logistics management in the context of digital transformation.

Keywords: logistics, digital transformation, real-time monitoring, transportation, IoT, GPS, supply chain management, logistics analytics.

Introduction. Efficient logistics route management has become a pivotal aspect of modern urban transportation systems, particularly as the growth of e-commerce and just-in-time delivery services intensifies the demand for adaptive and intelligent routing (Rismanto & Judijanto, 2025). Conventional logistics operations still rely on static route planning, which is unable to accommodate real-time variations in traffic flow, weather conditions, or vehicle constraints (Danchuk & Hutarevych, 2024). These limitations often lead to longer travel times, increased operational costs, and higher fuel consumption, thereby undermining both economic efficiency and environmental sustainability (Hussain, 2025). Addressing these challenges requires intelligent systems capable of processing and analyzing dynamic, multi-source data to support continuous decision-making under changing operational contexts (Chen et al., 2024).

Artificial Intelligence (AI) has emerged as a transformative approach in this domain (Badrinarayanan, 2024). Through machine learning and predictive modeling, AI enables systems to analyze historical and real-time data to anticipate traffic congestion, forecast demand, and optimize vehicle routing dynamically (Dikshit et al.,2023). Such models can continuously adapt to evolving conditions, ensuring that delivery operations remain efficient and reliable (Sihotang et al., 2024). Complementing this capability, Web-based Geographic Information Systems (Web-GIS) facilitate spatial data visualization and interaction, allowing logistics operators to monitor fleet movement, evaluate route alternatives, and perform spatial analysis directly through web interfaces (Vemuri et al., 2024). The synergy between AI and Web-GIS thus provides a strong foundation for developing intelligent, adaptive, and data-driven logistics management systems (Banu, 2025).

Previous research has explored AI-driven route optimization and Web-GIS-based logistics monitoring independently (Munawar, 2023). However, most existing systems treat these components as separate modules, resulting in fragmented data flows and limited responsiveness to real-time events (Eze, 2025). Furthermore, empirical studies evaluating the combined effect of AI predictive algorithms and GIS-based visualization in realistic logistics scenarios remain scarce (Hussain, 2025). Few studies have quantified the impact of such integration on measurable performance indicators, such as travel time reduction, route optimization speed, and energy efficiency, within dynamic traffic environments (Rismanto & Judijanto, 2025). This absence of empirical validation highlights a critical gap in the current literature on smart logistics systems (Chen et al., 2024).

The present study addresses this gap by designing and evaluating an integrated AI and Web-GIS-based real-time logistics route optimization system through simulation experiments. The proposed system combines classical shortest-path algorithms with AI-driven predictive modeling to generate and adjust delivery routes dynamically based on live traffic and vehicle data. The Web-GIS interface enables real-time visualization of vehicle movement and route status across urban logistics networks, supporting rapid decision-making and situational awareness. Simulation-based evaluation using real-world datasets demonstrates the system's potential to enhance operational efficiency, reduce fuel consumption, and improve delivery transparency. Through this integrated framework, the study aims to contribute to the development of scalable and sustainable logistics solutions driven by intelligent geospatial analytics. This paper does not present experimental results but focuses on the conceptual design and simulation planning of an AI and Web-GIS integrated system. The objective is to provide a structured framework and methodological guideline for subsequent empirical evaluation.

Literature Review. Artificial Intelligence (AI) has become a key enabler of intelligent logistics systems by allowing continuous data-driven decision-making in dynamic transportation environments (Prof & Pradhan, 2025). Within logistics routing, AI models process complex datasets such as vehicle telemetry, delivery constraints, and real-time traffic conditions to optimize paths and minimize operational delays (Egbuhuzor et al., 2023). Studies have shown that AI-based algorithms achieve higher routing accuracy and efficiency compared with conventional static methods by adapting routes according to live sensor and GPS data (Badrinarayanan, 2024). Predictive learning models have also been proven effective in forecasting congestion patterns and scheduling deliveries according to evolving network conditions (Paul et al., 2024).

Research on predictive analytics demonstrates that AI enhances logistics performance through continuous learning from both historical and streaming data (Zhang, 2024). Machine learning techniques including neural networks and reinforcement learning have been used to estimate travel time, detect anomalies, and optimize fleet utilization (Hussain, 2025). These adaptive algorithms contribute to stable and responsive logistics operations, particularly under uncertain or time-sensitive conditions (Egbuhuzor et al., 2023). The predictive nature of AI systems improves the ability of logistics networks to anticipate and mitigate disruptions, ensuring consistent delivery performance (Pathuri, 2024).

Web-based Geographic Information Systems (Web-GIS) have simultaneously advanced spatial analytics and visualization capabilities for logistics management (Vinnakota, 2022). Web-GIS platforms provide interactive access to geospatial information, enabling operators to monitor fleet locations, analyze traffic distribution, and visualize route performance in real time (Yerra, 2024). System architectures incorporating shortest-path algorithms such as Dijkstra's have demonstrated the effectiveness of Web-GIS for optimizing traffic flow and vehicle assignments in urban delivery environments (Mohsen, 2024). The visualization and analytical power of Web-GIS enhances situational awareness, allowing logistics planners to make faster and more accurate decisions (Fatorachian et al., 2025).

Integration between AI and Web-GIS technologies is increasingly recognized as a foundation for developing smart and sustainable logistics frameworks (Mandal & Mohammed, 2024). The combined use of AI-driven optimization and GIS-based visualization enables route recalculations that account for environmental and operational variables, reducing detours and idle time (Ojadi et al., 2024). This integration contributes to energy-efficient transportation, lower carbon emissions, and improved utilization of fleet resources (Hussain, 2025). By merging predictive modeling and spatial analytics, AI–Web-GIS systems provide an intelligent infrastructure for green logistics management (Mohsen, 2024).

Despite extensive research on AI and Web-GIS individually, empirical evaluations of fully integrated systems remain limited (Badrinarayanan, 2024). Most studies continue to develop AI optimization and GIS visualization as separate components, which results in fragmented data pipelines and delayed responsiveness to real-time events (Paul et al., 2024). Evaluations of algorithmic performance are often conducted in isolation without measuring their combined effect on end-to-end logistics operations (Prof & Pradhan, 2025). Few studies have quantified improvements in travel time, optimization speed, or energy efficiency that result from direct integration between AI models and Web-GIS interfaces (Fatorachian et al., 2025). This lack of empirical validation highlights the need for a unified simulation-based evaluation of AI–Web-GIS systems capable of supporting dynamic route optimization and real-time logistics monitoring (Zhang, 2024).

Research Methods. The research method is structured to define the system design and plan the simulation scenarios rather than to perform a complete empirical validation. Each phase aims to establish a reproducible blueprint for future experimental implementation. This study employed a mixed-methods approach consisting of system design, implementation, and simulation-based evaluation. The methodology was structured to produce an integrated framework that combines Artificial Intelligence and Web Geographic Information Systems for real-time logistics route optimization. Each phase was specified to ensure operational efficiency, adaptability, and scalability for practical logistics environments.

System Design. The system architecture comprises two tightly coupled layers, namely the AI optimization layer and the Web-GIS visualization layer. The AI layer analyzes dynamic inputs such as traffic flow, vehicle position, and delivery constraints to generate routing solutions that can be recalculated when conditions change. The Web-GIS layer provides spatial visualization and real-time monitoring of delivery routes, enabling operators to track vehicle movement and assess network conditions through interactive mapping. The two layers communicate through a bidirectional web service interface that synchronizes analytical outputs and geospatial rendering. The overall structure and data paths are summarized in Fig. 1.

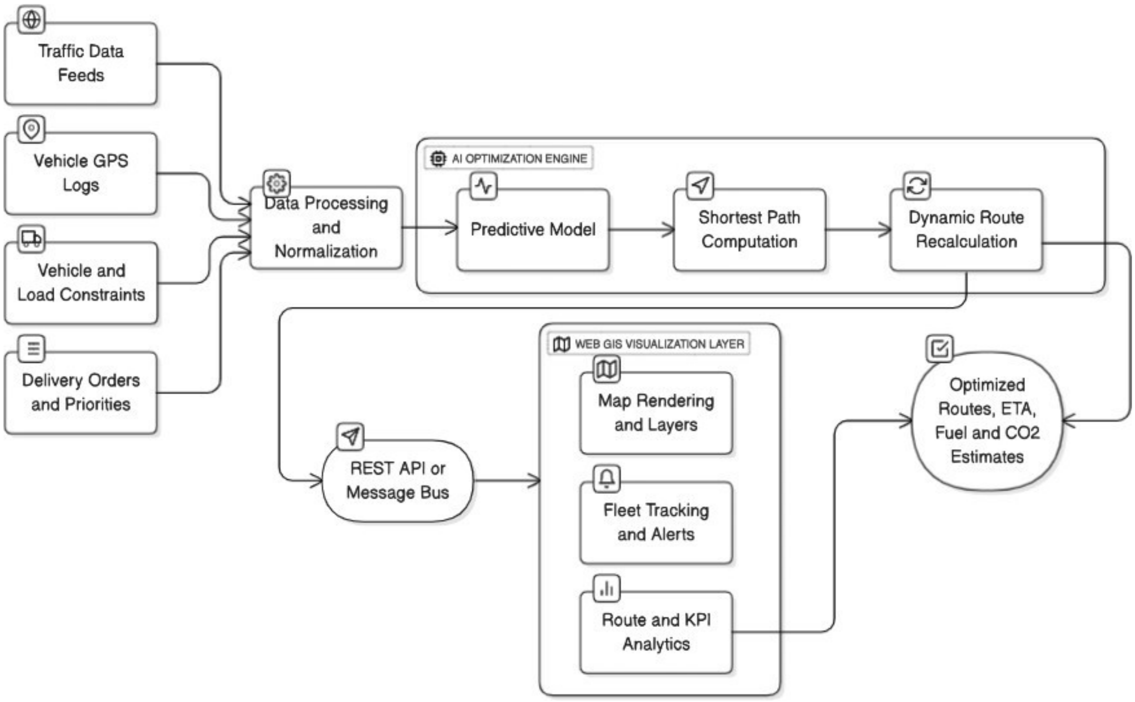

Fig. 1. System Architecture of the AI–Web-GIS Integrated Logistics Optimization Platform

Implementation Architecture. The implementation is organized into three modules, namely data processing, route optimization, and visualization. The data processing module collects and normalizes heterogeneous inputs from sensors, GPS devices, and traffic databases. The route optimization module applies an AI-driven routing engine that fuses predictive modeling with graph-based pathfinding to update routes when congestion or incidents occur. The visualization module renders updated routes and operational indicators on a Web-GIS interface. A modular interface enables horizontal scaling across fleets and depot configurations.

Dataset and simulation setup. Evaluation relies on controlled simulation experiments that emulate urban logistics operations. Datasets include road network topology, vehicle position logs, temporal traffic attributes, and delivery job specifications. Multiple scenarios are executed to represent varying congestion levels, vehicle capacities, and delivery priorities. Each scenario is run repeatedly to stabilize outcomes and to support statistical aggregation. The end-to-end evaluation workflow is summarized in Fig. 2.

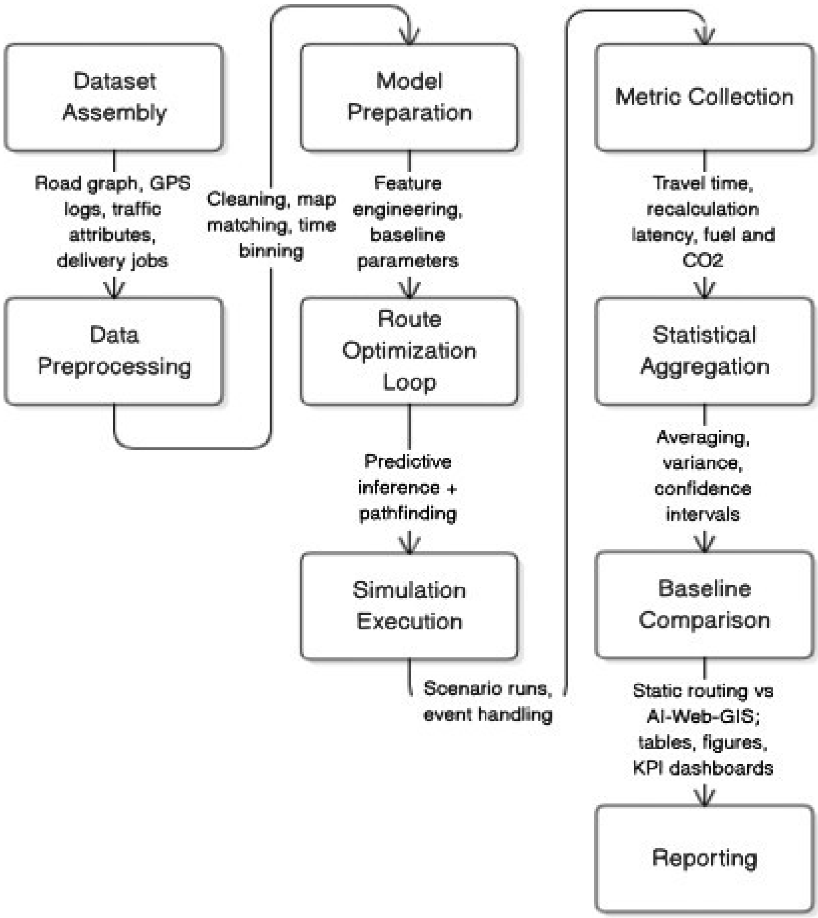

Fig. 2. Workflow of the Simulation-Based Evaluation Process

Evaluation Metrics. Performance assessment focuses on route optimization speed, average travel time, and computational efficiency. Additional measurements include estimated fuel consumption and carbon emissions to capture sustainability impact. Results from the proposed system are compared with a static routing baseline to quantify improvements across operational and environmental dimensions.

Validation procedure. Validation uses repeated runs under varying operational conditions. Identical datasets are applied across repetitions to control for input variance. Aggregated statistics are reported to mitigate randomness. Improvements in travel time and route recalculation speed are taken as evidence of adaptive capability, while stability across scenarios is used to argue for robustness and scalability.

Result and discussion. The proposed system is designed to demonstrate how the integration of Artificial Intelligence (AI) and Web-GIS can support real-time route optimization in logistics operations. The simulation plan emphasizes system adaptability, route recalculation capability, and visualization synchronization. Although no empirical testing has yet been performed, the simulation framework outlines expected performance characteristics under varying operational conditions. This section discusses the expected behavior and intended outcomes of the planned simulation.

System performance and route optimization. The AI optimization layer is planned to analyze traffic data, vehicle positions, and delivery priorities to generate adaptive routing solutions. The system is designed to dynamically recalculate routes whenever congestion, accidents, or delivery reassignments occur. Under the planned simulation, the AI module will process real-time traffic inputs to minimize idle time and total travel distance. The integration of predictive analytics and geographic data processing is expected to yield more efficient and context-aware route recommendations compared with static routing. These design expectations will serve as benchmarks for subsequent empirical validation.

Real-Time monitoring and responsiveness. The Web-GIS visualization component is designed to maintain continuous synchronization with the AI optimization engine. Within the planned simulation environment, route updates and vehicle locations will be displayed in real time on the interactive map interface. The system architecture is expected to ensure consistent data exchange between analytical and visualization layers, supporting responsive decision-making in simulated delivery operations. The visualization output will be used to evaluate how effectively the system can illustrate route recalculations, traffic density, and fleet distribution during simulated logistics activities.

Usability and transparency. The Web-GIS dashboard is planned to present delivery progress, route status, and estimated arrival times in a user-friendly format. This interface design aims to provide transparent access to operational data and to reduce uncertainty for both dispatchers and customers. During planned testing scenarios, the interface will be assessed for its ability to display route changes and maintain accurate delivery tracking. The color-coded map layers and visual indicators are expected to improve readability and operator situational awareness. This usability aspect is integral to validating the human–system interaction within the planned simulation framework.

Scalability and sustainability. The modular structure of the proposed architecture is expected to support diverse logistics scales, from small fleets to multi-regional networks. The simulation plan includes varying fleet sizes and route densities to assess scalability in processing multiple concurrent route updates. The architecture's modularity is designed to ensure consistent response times regardless of load variations. Moreover, by optimizing travel distance, the system conceptually contributes to fuel efficiency and reduced emissions, aligning with sustainable logistics principles. These expectations will be empirically verified in future testing once real data are applied.

System limitations and future validation Plan. The current design acknowledges certain limitations that may influence future implementation. The accuracy of route optimization depends on the reliability of GPS and traffic data streams, which can vary depending on external sources. The simulation framework does not yet incorporate stochastic variations such as communication latency or incomplete data feeds. These constraints will be considered in subsequent development phases. The present design phase aims to establish the framework, datasets, and metrics required for empirical validation, ensuring reproducibility when the system transitions from conceptual simulation to operational testing.

Conclusions. This paper presented the conceptual design and simulation planning of an integrated Artificial Intelligence (AI) and Web Geographic Information System (Web-GIS) for real-time logistics route optimization. The proposed architecture defines a modular interaction between the AI optimization layer and the Web-GIS visualization layer, designed to enhance adaptability, responsiveness, and scalability in logistics management systems. The framework focuses on combining predictive data processing with geospatial visualization to support intelligent and transparent route planning.

The simulation plan outlined in this study provides a methodological foundation for evaluating the expected performance of the proposed system. It specifies the parameters, scenarios, and metrics required for assessing how adaptive routing and real-time visualization can improve operational efficiency. Although no empirical testing has yet been performed, the planning process ensures reproducibility and establishes a clear roadmap for future implementation and validation under real-world conditions.

Through this design and simulation planning approach, the study contributes a structured framework that integrates AI-driven optimization and GIS-based monitoring within a single logistics platform. The proposed framework serves as a reference model for researchers and practitioners seeking to develop intelligent transportation and sustainable logistics systems capable of dynamic, data-driven decision-making.

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