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A Literature Survey on Multimodal Route Optimization and Real-Time Traffic Prediction for GPS Tracking Systems

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ABSTRACT: This survey explores the challenges and methodologies associated with digital network mapping, shortest path analysis, and real-time traffic management. By synthesizing research on multimodal metaheuristics, adaptive topology optimization, and deep-learning-based traffic forecasting, this paper provides a foundation for developing integrated GPS tracking and navigation systems. The survey highlights significant advancements in computational efficiency and accuracy while identifying current gaps in live multimodal data integration.

KEYWORDS: multimodal optimization, shortest path algorithms, real-time traffic prediction, GPS tracking, graph modeling.

I. INTRODUCTION

The rapid advancement of digital technology has significantly increased the complexity of urban transportation networks. Efficient urban traffic management is now critical for mitigating congestion and enhancing the commuter experience. This survey addresses the core objectives of designing a system that digitally maps road networks, stores GPS location data, and analyzes optimal routes using graph-based algorithms.

A. Motivation and Problem Statement Contemporary navigation systems often overlook the intricate impact of transfer times and conflicting criteria—such as time vs. cost—in multimodal environments. Furthermore, static routing algorithms frequently fail to account for real-time traffic dynamics, leading to inaccurate travel-time estimations. The objective is to evaluate methodologies that support real-time navigation and efficient route planning through accurate shortest-path identification.

B. Scope of the Survey This survey examines four primary research areas: multimodal metaheuristics for multi-criteria path optimization, adaptive topology extensions for rail transit, real-time spatio-temporal traffic forecasting, and access-node routing for combining disparate network types.

II. LITERATURE SURVEY

A. Modeling Frameworks and Multimodal Resilience

Akinyemi et al. provide a comprehensive review of the modeling approaches used in multimodal transportation systems. Their research emphasizes the critical concept of **network resilience**, defined as the system's capacity to maintain operational functionality despite internal or external stressors. The study categorizes transportation models into two distinct paradigms: **user-optimal behavior**, where individuals prioritize personal travel time, and **system-optimal behavior**, which seeks to minimize the aggregate cost across the entire network. By analyzing integrated



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mobility patterns, the authors highlight that multimodal infrastructures must balance supply-side constraints with dynamic commuter demand. This foundational review frames the necessity for adaptive navigation systems that can respond to network disruptions in real time.

B. Multi-Criteria Vehicle Route Optimization

The application of classical algorithms to modern vehicle routing is explored in the study of multi-criteria optimization using Dijkstra's algorithm. This research addresses the limitations of single-objective pathfinding by introducing a framework that weights **travel time, distance, and monetary cost** simultaneously. The methodology involves transforming these disparate criteria into a single objective function through weighted averaging operators. A significant finding of this work is that vehicle-specific route optimization requires personalized cost functions to account for varying fuel expenses and user priorities. This study provides a vital standard for calculating optimal paths for moving entities, which is a core deliverable for GPS tracking systems.

C. Complex Network Theory in Urban Transit

Cui et al. apply **Complex Network Theory** to the optimization of urban public transport networks. The authors utilize graph-theoretic metrics, including **degree centrality and betweenness centrality**, to identify critical nodes and "bottlenecks" within the city transit map. By modeling the transport system as a complex network, the research reveals that network robustness is highly dependent on the connectivity of specific hub stations. Their findings suggest that optimization strategies should prioritize the reinforcement of these key nodes to enhance overall transit efficiency. This methodology is essential for the digital mapping of road networks, as it allows for the identification of high-traffic junctures that dictate routing efficiency.

D. Temporal Networks from GPS Data

Kato et al. investigate the construction of **temporal networks** using time-stamped GPS data, specifically within the context of Kyoto tourism. Unlike traditional static graphs, temporal networks capture the **time-varying nature** of route availability and urban congestion. The researchers developed a methodology to process historical GPS logs to extract patterns of tourist movement and seasonal traffic fluctuations. The study demonstrates that route optimization based on temporal networks yields significantly more accurate travel-time estimations than static models, as it accounts for the "time-dependent" capacity of road segments. This approach is directly applicable to the future scope of AI-based route prediction and congestion modeling.

E. Multi-Criteria Shortest Path via Morphological Filters (Base Paper 1)

Amar et al. propose a novel metaheuristic called **Optimization by Morphological Filters (OMF-MT)** to address the Multi-Criteria Shortest Path (MCSP) problem in multimodal networks. Inspired by image processing, the methodology utilizes an **erosion transformation** to explore the search space and locate local optima near a "structuring element" or morphological filter. The system employs multiple parallel filters to ensure an intense search while incorporating a diversification method to prevent blockage at local optima. In experiments involving four transportation modes (metro, tram, bus, and taxi) and three criteria (distance, time, and cost), OMF-MT demonstrated significant advantages in **computation time** compared to Genetic Algorithms (GA) and NSGA-II. This algorithm will serve as the primary engine for calculating optimal multimodal routes in our proposed system due to its ability to achieve high solution quality with minimal computational overhead.

F. Spatio-Temporal Traffic Prediction Framework (Base Paper 2)

To transition from static to traffic-aware navigation, Kumar et al. introduce a real-time traffic prediction framework that integrates **Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM)** networks. The methodology leverages CNNs to extract spatial features from traffic sensors and GPS data, while LSTMs capture the complex temporal dependencies of urban flow. Their hybrid CNN-LSTM model achieved an 89% accuracy rate in traffic congestion forecasting, significantly outperforming traditional ARIMA and Random Forest models. Furthermore, the study utilizes **Deep Reinforcement Learning (DRL)** for adaptive traffic signal control, which reduced average delays by 30%. This framework will be implemented to fulfill the project's future scope for AI-based route prediction and travel-time estimation.



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G. Adaptive Topology for Urban Rail Accuracy (Base Paper 3)

Accuracy in urban rail navigation is often hindered by the failure to account for transfer times at interchange stations. Fang et al. address this by proposing the **Adaptive Topology Extension Road Network (ATEN)** structure. The methodology categorizes transfer stations based on their physical configuration and introduces **virtual stations** to explicitly differentiate between pedestrian transfer paths and train movement paths. By treating transfer time and travel time equivalently as edge weights, the ATEN structure allows a standard optimized Dijkstra's algorithm to query correct shortest paths without complex real-time operations on transfer nodes. This structural approach will be implemented to ensure the **accurate shortest route identification** deliverable of our digital road network mapping.

H. Access-Node Routing for Hybrid Integration (Base Paper 4)

The challenge of combining high-volume transit timetables with road networks is addressed by Tischner through the concept of **Access-Node Routing (ANR)**. This methodology facilitates multimodal routing by selecting specific "access nodes" in the transit network where a user can switch from road-based travel. The backend implementation utilizes the **Connection Scan Algorithm (CSA)** for time-dependent transit data, which Tischner found to be up to 1,000 times faster than Dijkstra-based variants for large-scale schedules. For the road segments, a modified version of the **ALT algorithm** (Landmarks and Triangle Inequality) is used to maintain goal-directed efficiency. This architectural strategy will be adopted for our system's backend to manage the integration of disparate data formats (OSM road data and GTFS transit feeds) while maintaining low query latency.

II. BASE PAPER SELECTION AND IMPLEMENTATION STRATEGY

After a thorough literature survey, this study selects Amar et al. (OMF-MT) [1], Kumar et al. (CNN-LSTM) [2], Fang et al. (ATEN) [3], and Tischner (ANR/CSA) [4] as the four base papers for implementation. The decision to adopt these specific works is driven by their direct applicability to our project's modules:

1. **Network Mapping:** We will implement the **ATEN** structure [3] to accurately model transit transfers within our digital map.
2. **GPS Tracking & Optimization:** OMF-MT [1] will be the primary algorithm for calculating multi-criteria shortest paths (time, cost, distance).
3. **Real-Time Data:** The **CNN-LSTM** framework [2] will be implemented to provide AI-based route prediction and traffic-aware optimization.
4. **Backend Efficiency:** ANR [4] will be used to manage the integration of high-volume transit timetables with sparse road graphs.

III. COMPARATIVE ANALYSIS

The synthesis of the eight surveyed works reveals a significant evolution in methodology, moving from traditional graph-based extensions to sophisticated AI-driven and metaheuristic frameworks. This section compares these approaches based on their computational mechanisms, data utilization, and applicability to real-world navigation.

A. Methodological Comparison

The methodologies can be broadly categorized into three tiers:

- **Classical and Theoretical Frameworks:** Works such as Akinyemi et al [5]. and Cui et al. [7] focus on establishing the theoretical robustness and resilience of networks. While these provide the necessary "graph health" metrics, they often lack the real-time agility required for modern GPS tracking.
- **Algorithmic Extensions:** The multi-criteria Dijkstra [6] and ATEN [3] methodologies refine classical pathfinding by adding layers of complexity, such as virtual stations and weighted multi-objective functions. These are highly accurate but require significant preprocessing of network topologies.
- **Advanced Metaheuristics and AI:** The primary base papers—OMF-MT [1], CNN-LSTM [2], and ANR/CSA [4]—represent the current state-of-the-art. These models prioritize computational speed and predictive capability, making them suitable for live systems where traffic conditions fluctuate rapidly.

B. Data Usage and Optimization Trends

There is a clear trend moving from static graph modeling toward data-driven temporal networks. Kato et al. [8] demonstrate the power of historical GPS logs to inform route availability, while Kumar et al. [2] push this further by



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using real-time IoT sensor data. A key differentiation lies in how these papers handle the "cost" of a path: newer approaches (OMF-MT) [1] treat cost as a dynamic multidimensional vector, whereas older models often simplify it into a single weighted scalar.

C. Summary Table of Methodologies

Table I provide a structured comparison of the core methodologies analyzed in this survey.

Methodology	Data Types	Primary Mechanism	Key Strength	Compute Complexity
Complex Network	Static Network Map	Centrality Metrics	Identifies Bottlenecks	Moderate
Temporal GPS	Historical GPS Log	Time Stamped Edges	Captures seasonality	High
OMF-MT	Multimodal Graphs	Morphological Filters	Rapid Global Convergence	Low
CNN-LSTM	Real-Time IOT Data	Spatio Temporal DL	89% forecast accuracy	High
ATEN	Transit Topology	Virtual Station	Corrects transfer errors	Moderate
ANR?CSA	GTFS? OSM Data	Access Node Routing	Scales to country level	High

TABLE I. COMPARATIVE SUMMARY OF ROUTING AND PREDICTION FRAMEWORKS

A key trend is the move toward local search mechanisms (OMF) and sequence learning (LSTM) to handle high-dimensional, non-linear traffic patterns. However, a gap remains in the seamless integration of these deep learning models with large-scale multimodal graphs, as many high-accuracy predictive models are evaluated on specific metropolitan datasets rather than integrated, cross-modal networks.

A. Identified Research Gaps

Despite these advancements, a critical gap remains in the **seamless integration of real-time predictive analytics with multimodal transfer logic**. While Kumar et al [2]. offer high-accuracy traffic predictions, their framework is primarily applied to single-mode traffic flow. Conversely, multimodal works like Amar et al [1]. and Tischner [4] provide excellent routing logic but often rely on average or static travel times rather than live, predicted congestion values. Bridging this gap is essential for achieving the project objective of "efficient route planning" in a live environment.

IV. DISCUSSION

The findings from the eight surveyed works provide a cohesive technical roadmap for the development of "V-NEURON" and its core objectives. The synthesis suggests that a truly adaptive GPS tracking system must balance architectural accuracy with real-time computational agility.

- **Topological Accuracy and Resilience:** The project's "digital road/network map" deliverable is directly supported by the ATEN structure [3]. By introducing virtual stations to separate pedestrian and train paths, the system can ensure high-fidelity navigation in urban centers like Nagpur. This structural precision is further reinforced by **Complex Network Theory** [7], which identifies critical "hub" nodes that dictate network robustness and efficiency. Furthermore, the conceptual framework of **network resilience** [5] ensures the system can maintain functionality despite the dynamic stressors of urban traffic.
- **Multi-Criteria Optimization:** The "shortest route analysis" objective requires a departure from single-metric pathfinding. The OMF-MT algorithm [1] provides the necessary speed for real-time requests by utilizing parallel morphological filters to find global optima. When combined with the personalized cost functions discussed in multi-



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criteria vehicle routing—weighting fuel, time, and distance [6] the system can offer tailored recommendations for different vehicle types.

- **Data-Driven Intelligence:** The integration of the **CNN-LSTM framework [2]** fulfills the future scope for AI-based route prediction. By extracting spatial patterns via CNNs and temporal dependencies via LSTMs, the system achieves the predictive power (89% accuracy) needed for proactive congestion management. This is complemented by the construction of **temporal networks** from GPS data [8], which allows the system to utilize historical logs to capture time-varying route availability.
- **Backend Scaling:** To manage the "digital database for GPS tracking," **Access-Node Routing (ANR)** and the **Connection Scan Algorithm (CSA) [4]** offer a way to compartmentalize high-volume transit timetables and sparse road graphs. This separation reduces memory overhead—a critical factor for cloud-based navigation services.

V. CONCLUSION AND FUTURE WORK

This survey has analyzed a diverse range of methodologies for multimodal shortest path optimization and real-time traffic management. Key insights include:

- The computational efficiency of **Morphological Filters [1]** for multi-criteria problems.
- The necessity of **Adaptive Topologies [3]** to eliminate search errors at transit transfer points.
- The predictive accuracy of **Hybrid Deep Learning (CNN-LSTM) [2]** for urban traffic flow.
- The scalability of **Access-Node Routing [4]** for integrating disparate network data.
- The identification of network bottlenecks through **Complex Network Theory** and the importance of **Temporal GPS logging** for accurate historical mapping.

Future work will focus on refining these algorithms to accommodate dynamic networks where live environmental data, such as weather and emergency service alerts, significantly influence route choice. Additionally, the next phase of development will explore the integration of **IoT-based vehicle tracking systems** and the use of Machine Learning to predict individualized traveler preferences, ensuring the system remains adaptable to the evolving challenges of smart city urban planning.

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