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Research Article

AI-Powered Digital Mobility Solutions for Sustainable Urban Transport

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Abstract – Transportation has emerged as a fundamental component of contemporary urban life, and its digital transformation is rapidly advancing through the integration of artificial intelligence (AI) technologies. The incorporation of AI into transportation systems presents valuable opportunities to enhance travel efficiency, reliability, and environmental sustainability. This paper introduces a comprehensive model aimed at the digitalization of transportation in the city of Yozgat, Turkey, by employing AI to improve and modernize the existing transit infrastructure. Yozgat currently relies on a transportation network composed of public buses, an intercity bus terminal, and a high-speed train station. However, several challenges have been identified, including irregular and unpredictable bus schedules, the lack of micro-mobility options, and limited taxi availability. To address these shortcomings, the proposed model integrates AI-driven technologies to develop a more efficient, accessible, and user-friendly transportation system. The model includes real-time tracking and intelligent route optimization for public buses, the introduction of shared electric scooters and bike rental stations to diversify urban mobility options, and the development of a unified mobile application that connects intercity and local transit services, including the high-speed train station. Furthermore, AI algorithms are employed to analyse traffic conditions and user behaviour in order to recommend the most efficient travel routes. A consolidated digital payment platform is also introduced to streamline fare payments across all modes of transportation. This model aims to improve the overall efficiency and coordination of Yozgat's transportation system while encouraging the adoption of environmentally sustainable mobility practices. The study demonstrates that AI-powered transportation digitalization offers a viable and scalable solution for enhancing urban mobility in medium-sized cities.

Keywords – artificial intelligence, transportation, digitalization

I. Introduction

We are living in a time when a convergence of technologies is granting entrepreneurs access to innovation across all sectors of society [1]. The facilitative role of digitalization enables access to information, the generation of creative solutions, and the empowerment of individuals within systems, thereby enhancing social interaction and connectivity on a societal level [2]. The key elements that make a city attractive include quality of life, socio-cultural environments, economic opportunities, and access to essential services such as healthcare and education [3]. While increasing urban populations place pressure on infrastructure systems, emerging technologies and collaborative business models simultaneously promote a new understanding of urbanism and entrepreneurship centred on quality of life [4].

Within this framework, the concept of the smart city has emerged, based on the systematic and integrated use of digital technologies across various domains of urban life. Smart cities aim to improve the efficiency, accessibility, and sustainability of public services such as transportation, energy, healthcare, education, and governance through information and communication technologies (ICT) [5]. These cities provide direct interaction with residents -such as assisting with intra-city mobility planning- and also enhance service quality without user interaction in areas such as infrastructure maintenance, environmental management, and the organization of public spaces [3]. As an inevitable result of rapid urbanization, smart cities are evolving into socio-technical systems involving joint engagement of governments, citizens, private sectors, and entrepreneurs [6].

The concept of smart cities has been shaped since the 1990s to address increasing infrastructure stress, environmental degradation, and inadequacies in public services -gaining greater visibility with the development of ICTs [7]. While smart cities have been examined in various disciplines such as urban planning, public administration, environmental studies, computer science, and entrepreneurship, there is still no universally accepted definition [8, 9]. The core principle, however, remains the integration of diverse urban systems through digital infrastructure to create more efficient, liveable, and sustainable cities [3]. In this context, transportation stands out as one of the most fundamental and transformative components of smart city applications.

Transportation is not only a matter of physical movement but also one of accessibility and participation in the social, economic, and cultural life of the city [10]. While historically constrained by limited technologies and vehicle availability, today's transportation systems face challenges stemming from vehicle overpopulation, limited road and parking infrastructure, air pollution, traffic congestion, and high energy consumption [11]. In many cities, efforts are made to shift users toward public transport and to expand transit lines and capacities. However, for such efforts to be effective, transportation systems must undergo not only physical but also digital transformation.

In smart cities, transportation plays a central role in achieving environmental sustainability, energy efficiency, and improved quality of life for residents [12]. Smart Transportation Systems integrate technologies such as sensors, artificial intelligence algorithms, machine learning, geographic information systems (GIS), and genetic algorithms to enhance the efficient use of existing infrastructure. These systems aim to mitigate problems such as congestion, environmental degradation, high costs, and workload by enabling the real-time collection, analysis, and interpretation of transportation data [13]. Especially in public transportation, these systems offer capabilities to analyse route densities, determine vehicle capacities, and plan alternatives during peak hours [14].

The rapid development of intelligent transportation technologies in recent years has enabled cities to deliver more efficient services despite limited resources. According to the World Economic Forum (2011), approximately 20% of global energy consumption occurs in the transportation sector [15]. This statistic highlights the strategic importance of smart transportation not only in urban planning but also in the global effort to combat climate change. ICT-enabled demand management in urban transport has the potential to significantly reduce both individual and collective carbon footprints.

These technological approaches transform stored and processed transportation data into effective decision-support systems. Through such systems, urban managers can structure not only transportation services but also resource management, environmental planning, and economic strategies in a data-driven manner. However, smart mobility projects in the existing literature primarily focus on metropolitan contexts and remain limited in their application to medium-sized cities. Therefore, the application of AI-supported transportation models in cities such as Yozgat presents a significant opportunity to fill both theoretical and practical gaps. The lack of data-driven solutions for public transport routing in these contexts further underscores the relevance of this study.

In this regard, the present study proposes a model for AI-driven digital transformation of transportation infrastructure specifically for Yozgat, a city located in Turkey's Central Anatolia Region. In medium-sized cities like Yozgat, public transportation largely depends on fixed-route bus systems. Despite the existence of major transportation connections such as intercity bus terminals and high-speed rail, uncertainties persist within the local transit network. Issues such as buses that do not operate at certain hours, difficulty accessing taxis, the absence of micromobility options, and limited digital integration constrain intra-city mobility. The proposed model seeks to address these challenges by improving efficiency and expanding user-friendly, environmentally conscious transport options through AI-enabled technologies.

The main objective of this study is to demonstrate that digitalization and artificial intelligence are not only applicable in large metropolitan areas, but can also be effectively implemented in developing cities such as Yozgat. By doing so, it aims to provide a model that can serve as a reference for smart city transformation in similar urban settings.

II. Methodology and Implementation Framework

This study proposes an AI-assisted model for the digitalization of transportation in the city of Yozgat. The model is currently in the preparatory phase and has been developed theoretically due to the unavailability of historical public transportation data from Yozgat Municipality. As a result, hypothetical (sample) data were utilized during the model testing process. Once real-time data become accessible, the model is designed to be directly integrated into the city's transportation infrastructure.

A. *Theoretical Infrastructure and Data Requirements*

The foundation of the proposed model lies in recording historical transit density on public transportation routes in a structured database and analysing these records using Geographic Information Systems (GIS) and artificial intelligence algorithms. Once such a data infrastructure is established, it will be possible to predict future travel patterns based on past passenger movements, allowing for more efficient bus scheduling aligned with both demand and capacity. Accordingly, the study introduces a data collection strategy and a data processing model that lay the groundwork for digital integration when the system is implemented.

Each vehicle in the system should be registered with a unique identifier, license plate, vehicle type, and capacity as attribute data. Route density will be categorized based on temporal variations - weekday/weekend, day/night-and will be evaluated through weekly, monthly, and annual averages using coefficient-based weighting. Through analysis of trip-level densities, the time intervals with higher passenger demand can be identified, enabling accurate assignment of trip frequency and appropriate vehicle sizing. However, these evaluations require the establishment of a digital database and preliminary measurement activities specific to Yozgat.

B. *Hypothetical Data Modelling and Scenario Testing*

Due to the current lack of actual data, the testing phase of the model was conducted using a hypothetical sample dataset. Specifically, the model was tested with schedule data from the 4K bus route serving Eskişehir Technical University. The sample data covered trips between 07:20 and 13:05. This simulation aimed to verify the logical accuracy of the model's forecasting and planning algorithms and demonstrated that the system could assign vehicles based on a minimum 70% occupancy rate.

The model also incorporates dynamic routing capabilities. During low-demand periods, the system recommends redistributing lower-capacity vehicles across different routes or integrating them into on-demand transportation services, based on past demand patterns obtained via mobile applications or sensor-based data sources. This not only enhances cost efficiency but also ensures more responsive service tailored to user needs.

C. *Database Design and Relational Model*

As illustrated in Fig. 1, a structured relational database will be developed to support the operational backbone of the system. The database will consist of seven core tables: stop, route, vehicle, trip, street/avenue, key location, and zone. These tables and their relationships are designed to maintain data integrity for transportation planning and to serve as the foundation for an intelligent decision-support system.

The database schema is constructed as follows:

A vehicle may be assigned to multiple trips, but each trip can only be served by a single vehicle, forming a one-to-many (1:N) relationship.

A many-to-many (N:M) relationship exists between vehicles and stops, and between vehicles and routes, as vehicles can operate on multiple routes and pass through several stops. Junction tables such as vehicle stop and vehicle route will facilitate these associations.

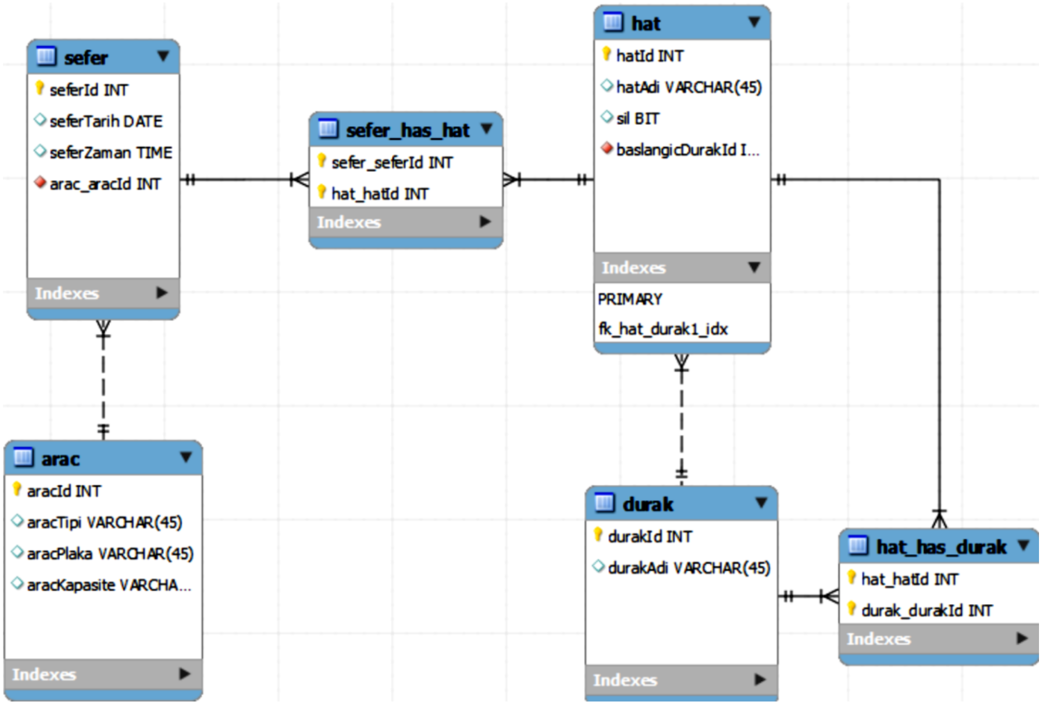

Fig. 1. The database schema [16]

Routes and stops also exhibit a many-to-many relationship, allowing the system to record which stops are included in each route and vice versa.

Each zone can contain multiple stops, but each stop belongs to only one zone, forming a one-to-many (1:N) relationship between zones and stops.

A many-to-many (N:M) relationship between key locations and entry exit records is established to store dynamic visitor density during different time intervals, particularly for locations such as hospitals, universities, or government institutions.

Real-time traffic density data for streets and avenues are also stored in the database and linked to specific zones. This enables comprehensive regional congestion analysis and enhances the accuracy of route optimization.

This relational structure is intended to facilitate integration with future real-time data sources, enabling multi-dimensional analysis of urban mobility and the refinement of AI-based forecasting systems. Moreover, the proposed architecture provides a scalable and adaptable digital infrastructure model not only for Yozgat but also for other medium-sized cities with similar transportation characteristics.

Vehicle-Trip Relationship: A one-to-many (1:N) relationship is established between the vehicle and trip tables, based on the assumption that a single vehicle can be assigned to multiple trips, but each trip can only be assigned to one vehicle. This structure allows for tracking which vehicle is assigned to each trip while also recording multiple trips performed by the same vehicle.

Vehicle-Stop and Vehicle–Route Relationships: Since a vehicle can pass through multiple stops and a stop can be served by multiple vehicles, a many-to-many (N:M) relationship is defined between the vehicle and stop tables. Similarly, vehicles can operate on multiple routes, and each route may involve several vehicles; thus, a many-to-many relationship is also established between the vehicle and route tables. For both cases, intermediate (junction) tables such as vehicle_stop and vehicle_route will be used to manage these associations.

Route-Stop Relationship: Recognizing that each route consists of multiple stops and that a stop can belong to multiple routes, a many-to-many relationship is defined between the route and stop tables. This design allows the system to query which stops are served by a given route and which routes pass through a particular stop.

Stop-Zone Relationship: Since a zone may include multiple stops, but each stop can only belong to one zone, a one-to-many (1:N) relationship is established between the zone and stop tables. This enables zone-based spatial analysis and service distribution evaluations.

Key Location–Entry/Exit Relationship: Key locations, such as universities, hospitals, and government buildings, experience fluctuating visitor density during different time intervals. Therefore, a many-to-many (N:M) relationship is designed between the key location and entry exit tables to store data on hourly entry and exit patterns, enabling time-based crowd density analysis at critical points in the urban environment.

Street Density and Zone Relationship: Real-time traffic density data for individual streets and avenues constitutes another essential component of the transportation dataset. These density records are stored in relation to corresponding zones, allowing not only for stop-level but also for street-level congestion assessments. This spatial linkage enhances the reliability of routing and travel time estimations in the AI-based decision-making process.

This structural model is designed to support future integration with real-time data sources, allowing for multi-dimensional analysis of urban mobility patterns and the advancement of AI-powered prediction systems. Furthermore, the proposed database design is not only tailored to Yozgat but can also serve as a scalable digital infrastructure model for other medium-sized cities with similar mobility characteristics.

III. RESULTS

This study proposes an artificial intelligence (AI)-driven model for the digitalization of the transportation system in Yozgat, one of Turkey's medium-sized cities, thereby demonstrating that smart mobility applications should not be confined solely to metropolitan areas. It emphasizes that in cities where public transportation infrastructure has not yet reached a sufficient level of digital integration, it is still possible to implement user-oriented, efficient, and sustainable transportation planning by leveraging information and communication technologies (ICT).

The model aims to digitally collect data related to mobility patterns and to integrate these datasets into decision-support processes through the use of AI algorithms and geographic information systems (GIS). Although the model has not yet been implemented in practice, the developed data collection strategy, relational database structure, and algorithmic framework reveal a solid foundation for practical deployment. Once historical transportation data from Yozgat Municipality is digitized and made accessible in an open-data format, the model can be tested and adapted to real-world conditions.

The proposed system allows for dynamic planning based on temporal variations and demand intensity, enabling the optimization of parameters such as vehicle capacity and trip frequency. Designed around a target occupancy rate of 70%, the system seeks to enhance both transport efficiency and passenger satisfaction. Furthermore, during low-demand periods, the model recommends flexible, mobile-based routing solutions to prevent resource inefficiencies. The hypothetical data scenario used during model validation demonstrates the algorithmic feasibility of the proposed framework.

One of the study's most significant contributions lies in its provision of a systematic roadmap for transportation planning in data-scarce cities. In this respect, the model represents a replicable and adaptable solution for other medium-sized cities with similar structural characteristics. Future research should focus on completing real-time data collection processes, testing the model under operational conditions, comparing outputs with user behaviour, and enhancing the system's learning capabilities through machine learning techniques.

IV. CONCLUSION

This study presents a theoretical model for the digitalization of urban transportation systems in Yozgat, Turkey, through the integration of artificial intelligence (AI) and geographic information systems (GIS). Recognizing the limitations of mid-sized cities in terms of transportation infrastructure and data availability, the proposed model offers a structured roadmap for how data-driven, AI-powered transportation planning can be introduced even in regions lacking digital systems. Although real-world data from Yozgat Municipality is not yet accessible, the model is built to function upon the establishment of a foundational transportation database.

The study highlights the need to digitally record and analyse public transportation data -such as bus capacities, stop densities, and passenger flows-using machine learning techniques. By utilizing predictive analytics, the system aims to dynamically adjust routes and vehicle assignments to ensure efficiency and passenger satisfaction. Through hypothetical data testing, the model has demonstrated its potential to maintain a minimum 70% vehicle occupancy rate and to recommend dynamic routing during off-peak hours, thus optimizing both cost and resource use.

In conclusion, this model contributes a scalable and adaptable framework for implementing smart mobility solutions in medium-sized cities. Once real-time and historical transportation data is collected, the model can serve as a functional decision-support system that enhances mobility, promotes environmental sustainability, and improves the overall quality of urban life. Future research should focus on piloting the system in collaboration with local governments, integrating live data streams, and refining the AI algorithms to better adapt to evolving transportation patterns and user behaviour.

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