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Full Papers

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Enhancing Sustainability in Logistics, Transport, and Supply Chain Management

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Welcome



It is my pleasure to welcome you to CILT(UK)'s Annual **LRN Conference 2025**. This year's theme is all about **'Enhancing Sustainability in Logistics, Transport & Supply Chain Management'**. Together with our inspiring speakers, we will explore pioneering research and thought leadership that address today's most pressing challenges - from environmental impact and sustainability to technological innovation and the future of skills.

As academics and professionals working in some of the most dynamic and vital fields of our economy, your contributions are driving progress. From supply chains and shipping lanes to last-mile deliveries and advanced logistics technologies. From buses and trains to airlines and digital mobility platforms. Your research and innovation underpin the systems that ensure goods and people move efficiently, shelves remain stocked, businesses stay resilient, communities remain connected, and societies thrive through accessible and reliable transport.

The strength of our profession lies not only in the systems and technologies we build, but in the ideas, knowledge, and discoveries that continue to advance them.

Thank you for joining us, and I hope you enjoy the event.

Helen Hardy FCILT

Chief Executive Officer (Interim) CILT(UK)

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A LITERATURE REVIEW OF STATISTICAL AND AI-BASED METRO PASSENGER DEMAND FORECASTING MODELS

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Purpose

This study contributes to the NEXUS project, an EU-funded initiative focused on enhancing metro operations through AI, data science, and advanced forecasting. Recognizing the challenges posed by fluctuating passenger demand, disruptions, and evolving passenger behaviours, this research explores improved demand forecasting methodologies to support adaptable and sustainable metro systems.

Research Approach

The research conducts a comprehensive review and analysis of both traditional statistical methods and emerging AI-based models for passenger demand forecasting in metro operations. Quantitative approaches including ARIMA, SARIMA, probabilistic regression, and deep learning models such as neural networks, generative adversarial networks (GANs), and graph-based attention networks are examined. These methods are evaluated for their applicability across different forecasting horizons and operational contexts, with particular attention to their performance under data-limited or expansion scenarios.

Findings and Originality

While traditional statistical models remain effective for short- and medium-term forecasting where historical data is available, they face limitations in dynamic environments such as new station planning and network expansions. In contrast, AI-based models especially those leveraging deep learning, hybrid approaches, and alternative data sources demonstrate superior adaptability and predictive performance in complex, non-linear, or data-sparse contexts. This work advances the NEXUS objective by identifying innovative techniques that can enhance forecasting accuracy and operational decision-making in modern metro systems.

Research Impact

The findings directly support ongoing NEXUS pilot studies in Genoa (Italy) and Sofia (Bulgaria), providing methodological foundations for integrating AI into real-time demand forecasting, timetable optimization, and operational planning. The research informs the development of adaptive control frameworks capable of responding to fluctuating demand with improved resource allocation, service quality, and passenger satisfaction.

Practical Impact

The research will make metro operations more flexible and responsive to demand, reducing overcrowding and underutilised services. Improved vehicle utilisation and increased capacity will lead to cost savings and energy efficiency. The study aims to optimise passenger flow, reduce dwell times, and improve service quality, promoting inclusivity, accessibility, and reducing reliance on private vehicles.

Keywords

metro systems, passenger demand forecasting, intelligent transportation, artificial intelligence, transport planning

Introduction

Demand forecasting, often conflated with Passenger flow prediction, plays a critical role in the strategic and operational functions of railway systems (Milenković & Bojović, 2016). It serves as a foundational element for the planning and managing key domains such as transport operations, infrastructure development, and service provision. As Nguyen et al. (2020) highlight, the forecasting of passenger flow demand is particularly effective in optimizing metro service schedules, improving passenger flow management, and supporting effective policymaking and planning. Accurate demand forecasting enables railway operators to align transport supply with anticipated demand, thereby enhancing overall system efficiency. Milenkovic, et al, (2013) also emphasised that a thorough understanding of existing passenger travel patterns is essential to identify and analyse existing traffic related challenges.

The influx of passengers during peak hours whether predictable, as in morning and evening commutes, or unexpected places significant strain on the railway system. These fluctuations often lead to congestion, service delays and operational inefficiencies. As a result, metro operators frequently encounter difficulties to provide services that effectively balance efficiency, cost-effectiveness and passenger satisfaction

Despite its importance, demand forecasting is inherently limited by its inability to account for all future uncertainties. Unforeseen factors can significantly impact the accuracy and reliability of forecasts (Milenković & Bojović, 2016).

Demand forecasting horizons are classified into three types as shown in Table 1: Long term forecast which look ahead to 5 to 10 years. Medium term forecasts which extend from 2 to 5 years into the future and Short-term forecast which predicts intervals between 6 to 18 months (Feng, et al, 2021). Outputs from short-term forecasting in particular plays a crucial role in immediate operational planning such as minute-based highway forecasting or hour based, or daily based forecasting for seat allocation in railways (Tsai & Wei, 2009). It is no surprise therefore that, Celebi, et al, (2009) highlight short term forecasting as the key to the success of transportation planning and management like timetabling and resource allocation.

Time Horizons	Time frame	Focus
Long- term forecast	5-10 years	Strategic investments
Medium -term forecast	2- 5 years	Planning
Short -term forecast	6-18 months	Operations

Table 1: Classification of demand forecasting. (Extracted from Feng et. al, 2019)

This paper explores a wide range of techniques used in demand forecasting for metro and urban rail operations, highlighting key methods and advancements, while also examining emerging trends in forecasting passenger demand. This study adopts an integrative narrative literature review approach to examine existing research on metro demand forecasting methods with a primary focus on quantitative techniques. It reviews a diverse range of forecasting models presented in peer-reviewed journals. The selected studies are organized by methodological approach, encompassing both statistical methods (e.g., ARIMA, Box-Jenkins, regression models, and probabilistic models) and artificial intelligence-based techniques (e.g., neural networks, random forests, support vector regression, generative adversarial networks, and graph-based deep learning). The findings are summarised in a comparative table highlighting the forecasting techniques employed, their horizons, and key methodological innovations.

Literature Review

Over the past decades, an extensive body of research has been contributed to enrich the forecasting approaches of urban rail transit. Both qualitative approaches—such as the Delphi method, economic surveys, and analogical techniques—and quantitative methods have been used over time to forecast demand (Bai, 2016). Nonetheless, more interest has increasingly gravitated towards quantitative method of urban rail demand forecasting (Fang et. al, 2019).

Commonly used methods for rail transit demand forecasting include the traditional models, statistical models, machine learning, and simulation software. Recent research has brought more attention to machine learning techniques which is a subset of artificial intelligence to accurately forecast passenger demand in transportation as a whole.

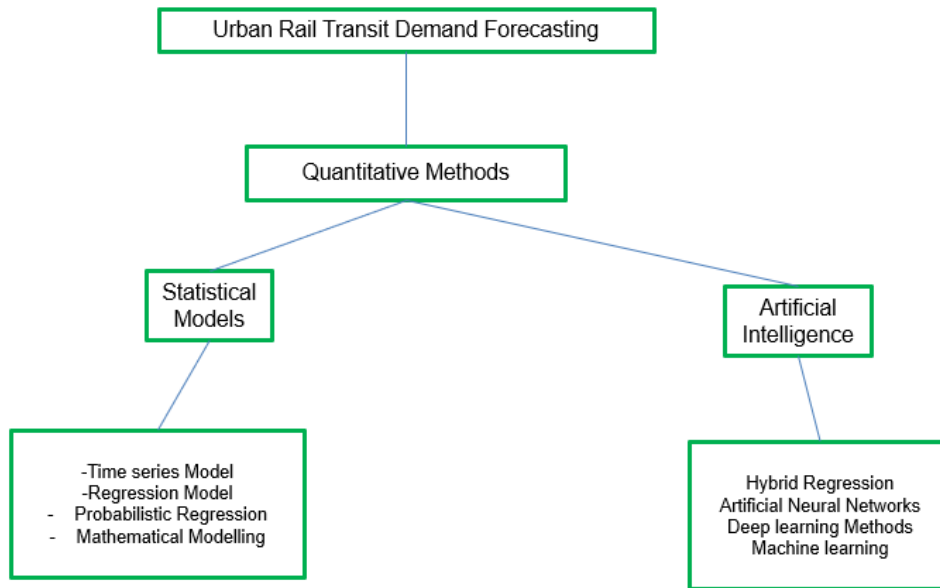


Figure 1: Classification of methods used in Urban rail demand forecasting (Adapted from Fang et.al, 2019)

Since there is limited research applying qualitative methods or traditional approaches in recent developments, this report focuses on quantitative techniques specifically those involving statistical models and artificial intelligence or passenger demand forecasting. Figure 1 illustrates various quantitative methods of demand forecasting pointing out the growing use of artificial intelligence as a key future trend. Contemporary research explores AI-based methodologies to improve forecasting precision.

Statistical Method of Demand Forecasting

Numerous studies have employed traditional statistical methods in which demand of passengers are predicted in railway systems, including linear regression, time series analysis, trending models, exponential smoothing, moving average, and the AutoRegressive Integrated Moving Average, ARIMA (Halyal, et.al, 2022). In general, Demand Forecasting methodologies can be both qualitative and quantitative. Qualitative forecasting relies on insights provided directly by railway operators, while quantitative methods leverage historical data to identify trends and patterns. Table 2 shows a summary of studies on the use of statistical methods for passenger demand forecasting in urban rail transit.

Mendhe et al. (2025) presented a comprehensive study utilising ARIMA models to predict passenger traffic in metro systems using ticket reservation data from Pune Metro system, India. These ARIMA models identified seasonal trends and seasonal variations in ridership, enabling accurate predictions of passenger flow patterns.

Anvari et al. (2016) developed a time series forecasting framework based on Box-Jenkins methods for public transportation systems and the model was tested on real passenger traffic data from Istanbul Metro. The results showed that the proposed framework is very effective and gives a higher accuracy compared to other models referenced in the study's literature review. Based on Box-Jenkins, ARIMA model is found to be best suited for forecasting long term passenger demand and one of the most widely used time series models (Zhang, 2003).

Kato et. al. (2017) developed a well-calibrated, accurate model to forecast urban rail travel demand in Tokyo's metropolitan rail network which included a rail-station access/egress model and took accounts of changes in socio-demographic patterns using mathematical modelling to help Tokyo's 15-year rail investment strategy.

In a comprehensive study, Tang et al. (2019) employed various forecasting models including time series models, ARIMA, linear regression, and support vector regression to predict short-term passenger flow at subway stations. The study utilised data collected through an automatic fare collection system. It aimed to evaluate the impact of temporal and spatial features, as well as external factors such as weather, on passenger flow forecasting.

To improve the granularity of temporal forecasts, Chuwang and Chen (2022) examined the comparative performance of ARIMA, Seasonal ARIMA (SARIMA), and the Facebook Prophet algorithm in predicting daily and weekly passenger demand. Their results suggested that Prophet outperformed SARIMA in daily forecasts, while ARIMA remained superior for weekly projections.

Milenkovic, et al, (2013) likewise applied the ARIMA in a state space form to forecast railway passenger traffic and model the rail passenger demand on Serbian railways addressing trends, seasonal and cycle variations providing a solid framework for modelling rail passenger traffic.

Alblooshi et al. (2024) investigated using three forecasting models SARIMA, Holt-Winters and Long Short-Term Memory (LSTM) to predict ridership demand for the Dubai Metro. SARIMA emerged the most accurate of the three models and effectively captured long trends and seasonal variations.

Guleria (2024) addressed the inaccuracies of forecasts in India particularly for the Delhi Metro due to unreliable travel demand models. It explores the application of probabilistic regression models especially the Gaussian, Negative Binomial, and log linear models to improve demand prediction.

Study	Statistical Method Used	Statistical tool	Main Innovation	Time Horizon
Mendhe et al. (2025)	Time Series Forecasting	ARIMA	Used ticket reservation data to forecast metro demand with seasonal accuracy	Short to Medium-term
Anvari et al. (2016)	Time Series Forecasting	ARIMA – Box Jenkins	High-accuracy long-term demand forecasting using real metro data	Long-term
Kato et al. (2017)	Mathematical Modelling	Custom demand model	Supported Tokyo’s 15-year rail strategy with a calibrated demand model	Long-term
Chuwang & Chen (2022)	Time Series Forecasting	ARIMA, SARIMA, Facebook Prophet	Compared models to identify best performers for daily and weekly demand	Short to Medium-term
Milenković et al. (2013)	Time Series Forecasting	ARIMA (State-Space)	Modelled rail demand accounting for seasonal and cyclical patterns	Long-term
Alblooshi et al. (2024)	Time Series Forecasting	SARIMA, Holt-Winters, LSTM	Identified SARIMA as best for long-term metro demand in Dubai	Long-term
Guleria (2024)	Probabilistic Regression	Gaussian, Negative Binomial, Log-Linear	Improved demand accuracy in India by correcting model bias from unreliable data	Medium-term

Table 2: Summary of studies on the use of traditional ways for demand forecasting in metro operations

Collectively, these studies affirm that statistical forecasting methods are popular and most effective when historical demand data is available, and particularly useful for medium- to long-term planning where recurring temporal patterns can be exploited. However, they also underscore a significant limitation: the inability to forecast demand at new or future stations lacking historical data. This constraint is especially problematic during metro system expansions or when planning for newly urbanised areas, scenarios in which statistical methods become insufficient. It is precisely in such contexts that artificial intelligence (AI) and data-driven modelling techniques offer a compelling alternative.

Artificial Intelligence (AI) in Demand forecasting

Artificial intelligence (AI) has emerged as a powerful complement to statistical methods in passenger demand forecasting, particularly in areas where conventional approaches lack flexibility or the capacity to handle complex, nonlinear, or data-sparse environments. Table 3 shows the summary of studies on the use of Artificial intelligence in demand forecasting in metro system.

In recent years, the integration of artificial intelligence, advanced statistical and machine learning techniques has transformed metro transit demand forecasting leading to greater accuracy and enhanced operational efficiency in urban rail systems (Alblooshi, et.al, 2024).

Celebi et. al (2009) applied neural networks to develop short-term passenger demand forecasting models to be used in the operational management of light rail services. Similarly, Nar & Arslankaya (2022) employed a hybrid approach combining regression analysis with machine learning algorithms, including artificial neural network to forecast passenger demand. Their study addressed demand prediction on both line and station levels, demonstrating the effectiveness of multiple techniques.

In the context of Thailand’s Metropolitan Rail Transit (MRT) Purple Line, Kusonkhum et. al. (2022) examined several machine learning algorithms such as artificial neural networks, random forests, and decision trees for demand forecasting. Their comparative analysis revealed that the artificial neural network model outperformed the others predictive accuracy, making it the most suitable for forecasting passenger demand on that rail line.

Ding et al. (2024) addressed the challenges of station level metro ridership prediction under expansion scenarios (MRP-E). They proposed a Metro-specific Multi-Graph Attention Network (Metro -MGAT) to predict long-term station level ridership during network expansion planning using data from Shanghai Metro, China.

Feng et al. (2021) proposed an improved Wasserstein Generative Adversarial Network (WGAN) model, a type of deep learning model, for railway passenger demand forecasting using web search terms data. The improved WGAN model can generate virtual data to expand real dataset and predict demand more effectively. Tests in Beijing revealed that changes in the web search behaviour precede changes in railway demand by about one month making it useful for early forecasting.

Gwon et al., (2024) focused on short-medium demand forecasting. The study presented a model for predicting hourly subway ridership based on weather conditions using three artificial intelligence algorithms - Multiple Linear Regression (MLR), Random Forest regression (RFR) and Multi-Layer Perceptron (MLP). Results showed the model outperformed the alternative models in accurately predicting subway ridership.

Study	Model/Method	AI tool	Main Innovation	Time Horizon
Celebi et al. (2009)	Neural Networks	Deep learning	Neural networks for short-term passenger demand	Short-term
Nar & Arslankaya (2022)	Hybrid Regression + ANN	Machine Learning	Combining regression and ANN for station/line demand forecasting	Short-term
Kusonkhum et al. (2022)	ANN, Random Forest, Decision Tree	Machine learning	Comparative analysis of ML methods; ANN best	Short-term
Ding et al. (2024)	Metro-MGAT	Deep Learning (Graph-based)	Long-term ridership forecasting under expansion scenarios	Long -term
Feng et al. (2021)	Improved WGAN	Deep Learning (GAN)	Forecasting railway demand using web search terms	Short to Medium-term
Gwon et al (2024)	MLR, RFR, MLP Comparison	Machine Learning	Predicting subway ridership with weather influence	Short to Medium-term

Table 3: Summary of research on the use of Artificial Intelligence for Demand Forecasting in Metro Operations

Although the body of research applying AI to passenger demand forecasting is still evolving, there is a clear and growing interest in leveraging deep learning and advanced machine learning techniques to overcome the limitations of traditional statistical models.

Conclusion

To conclude, traditional statistical forecasting models such as ARIMA and regression-based approaches remain effective for short-to medium-term metro demand forecasting when sufficient historical data exists. However, these models are limited in addressing network expansions and emerging demand patterns. Recent advances in artificial intelligence and machine learning, particularly deep learning and graph-based models, offer robust alternatives capable of capturing complex and dynamic passenger behaviours. The findings contribute directly to the NEXUS pilot studies in Genoa and Sofia, establishing methodological foundations for AI-driven real-time forecasting, timetable optimization, and operational planning. This progression enables metro systems to more effectively manage

demand variability, optimize passenger flow, reduce dwell times, and improve service quality and resource utilization. Ultimately, these innovations promote flexible, efficient, and sustainable metro operations, supporting cost savings, energy efficiency, reduced private vehicle dependency, and inclusive urban mobility.

Future Work

Future work will focus on selecting or developing a methodological framework to optimize demand forecasting models currently used in practice and research. Once the model is finalized, it will undergo further validation to assess its accuracy. The integration of machine learning techniques will also be explored to enhance predictive performance.

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