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Short-term Passenger Flow Prediction Research of Urban Rail Transit under Rainfall Conditions

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Abstract: The short-term passenger flow prediction in urban rail transit serves as a crucial basis for dynamic adjustments of transportation organizations, enhancing the efficiency of operational services and safety assurances, while effectively advancing the development of intelligent rail transit systems. By examining the impact of adverse weather conditions on rail transit passenger flow, conducting research on cloud models, and analyzing existing short-term passenger flow prediction models, this study proposes a novel concept for a short-term dynamic passenger flow prediction model based on cloud models under rainfall conditions.

Keywords: Short-term Passenger Flow Prediction, Rainfall Conditions, Cloud Model.

1. Introduction

Capitalizing on its punctuality, speed, safety, and comfort, as well as minimal interference with other ground transportation methods, rail transit is increasingly becoming the backbone of urban public transportation systems. The operation and management of rail transportation encounter new opportunities and challenges. As a fundamental aspect of operational management, short-term passenger flow prediction and analysis not only provide a reliable foundation for organizing passengers but also effectively mitigate congestion, enhance service quality, and improve the management and service capabilities of rail transit stations and the entire network.

Short-term passenger flow refers to the statistical data of passenger volume when the time granularity does not exceed 15 minutes [1]. Short-term urban rail transit passenger flow prediction, forecasting passenger volume for the next 5-15 minutes, is based on historical AFC (Automated Fare Collection) data. Urban rail transit passenger flow is influenced by various factors, including land use along the transit lines, socio-economic development, and the scale of the urban population. Among these factors, rainfall is a common weather-related element that causes fluctuations in passenger flow and significantly contributes to the uncertainty in rail transit passenger volume.

2. Research on Short-term Passenger Flow Prediction of Urban Rail Transit under Unfavorable Weather

2.1. Research on the impact of adverse weather on passenger flow in urban rail transit

Among the factors influencing fluctuations in urban rail transit passenger flow, adverse weather impacts passengers by forcing them to alter their travel plans and re-plan their routes. For instance, Khattak et al. discovered that under the influence of inclement weather, people change their commuting methods and routes, thus altering their travel behavior [2]. Kalkstein et al. examined various weather patterns and their effects on Chicago's rail transit passenger flow, observing different degrees of change and summarizing the laws governing passenger flow fluctuations affected by distinct weather conditions [3]. Outwater et al., through surveys of public transport passengers, found that nearly 12% of people in Salt Lake City intended to change their travel plans due to weather fluctuations and abandoned their original public transportation methods [4]. Zhu Chengcheng established a choice model for rail transit commuting methods to analyze the impact of rainfall on the probability of selecting such a method [5].

With ongoing in-depth research, it has become evident that different weather conditions and their timing have varying impacts on passenger flow. For instance, Stover et al. observed that diverse meteorological conditions have distinct effects on passenger flow across different seasons. Strong wind, rain, and snow, which negatively affect passenger flows, mainly occur in various seasons, with wind corresponding to spring and winter, and rain spanning all four seasons [6]. Lou Shurong used a moving average method to analyze the influence of weather observation factors, establishing a relationship model between rainfall, land use factors, and daily passenger flow at rail transit stations. The study found a positive relationship between the increase in passenger flow and the amount of rainfall, while the influence of rainfall during the day's peak period had a negative correlation with passenger flow [7]. Changnon discovered that during summer rain, bus and Chicago Transportation Administration passenger flows decreased by 2.1% and 3.5%, respectively, with the impact of rainfall on passenger flow being greater during early and late rain [8]. Liu Xintong studied the effects of rainfall on passenger flow during weekends, workdays, peak, and off-peak hours for bus passenger flow, finding that the impact of rainfall on passenger flow during early peak hours was not significant, while it had a considerable negative impact on evening peak hours [9]. To investigate the influence of rainfall on passenger flow, foreign scholars proposed using a benchmark value [10] and a nine-point moving average algorithm [11]. Research has shown that the accuracy of the passenger flow foundation obtained using these methods is the closest to the actual passenger flow patterns.

2.2. Cloud model research

Drawing from the concept of the cloud model, researchers like Di Kaichang and Li Deyi have utilized the cloud model to represent knowledge and discovery in the spatial database, continuously developing the cloud model from one-dimensional to two-dimensional, and beyond [12-13]. By comparing and summarizing existing reverse cloud algorithms, Jin Lu proposed a new reverse cloud algorithm that combines the advantages of other algorithms [14]. Yu Jiaojiao employed historical data as sample data to establish a cloud model-based short-term traffic flow prediction model and used real-time data to verify the reliability and accuracy of the predictive model [15]. Xu Shaohua and colleagues proposed a neural network model capable of converting the concept of describing or determining the relationship between objects into numerical variables based on cloud transformations and neural networks [16]. In decision-making, Wang Jun introduced a dual-expected decision-making method using the cloud model and the calculation method for the comprehensive similarity of the cloud model [17]. Yang Ping addressed the issue of solving group decision-making and established a cloud model-based multi-attribute group decision-making method. By utilizing a positive cloud model to represent decision-making information and extracting decision-makers based on comprehensive acquaintance calculations, unknown connections between existing decision-makers are revealed [18]. Zhang Huaitian introduced cloud models in traffic flow data mining and extracted traffic data based on concepts, discovering that the corresponding conceptual division algorithm should be applied according to the granularity of different data and concepts [19]. X.H.L proposed interval cloud models, as well as forward and reverse generators based on the affiliated cloud, representing a cloud with six numerical features [20]. Qin Kun simplified the method of impacting the concept of clouds between similar clouds to the cloud [21]. Some scholars have applied cloud model algorithms and reverse normal cloud algorithms to passenger flow prediction. By using peak cloud transformation algorithms to establish a cloud and passenger flow cloud, they have been able to describe the overall historical changes in urban rail transit flow and the likelihood of future passenger flow changes [22-24].

2.3. Short-term passenger flow prediction research

In response to short-term passenger flow prediction, scholars worldwide have conducted extensive research and achieved significant results. The prediction methods based on statistical theory include time series prediction models, Kalman filter models, multiple regression models, and the k-nearest neighbor algorithm (K-NN); methods based on artificial intelligence, such as neural networks, deep learning, and long short-term memory networks (LSTM); wavelet analysis based on non-linear theory; dynamic transportation prediction methods; and various combined models formed by integrating multiple prediction methods.

The ARIMA model can capture the long-term features of OD passenger flow distribution, making it less affected by short-term fluctuations. However, its drawback is that it is not well-suited for changes in OD passenger flow. With scholars continuously researching time series models, many improved models have been proposed, such as the Subset ARMA [25] model for short-term traffic forecasts and the Kohonen-ARIMA [26] model. Yang Jing combined the ARMA model with wavelet analysis, resulting in a hybrid model that outperforms a standalone ARMA model and boasts faster calculation speeds for short-term passenger flow prediction [27].

Based on the Kalman filter model grounded in linear filter theory, Zhang Zhiyong and colleagues improved the Kalman filter to achieve short-term passenger flow prediction while enhancing the real-time nature of the prediction information [28]. Xu Xinyue, Liu Liqiang, and others analyzed the spatial relationship of short-term passenger flow in urban rail transit networks, using convolutional calculations on images to uncover the cross-relationships of passenger flow among different stations and their spatio-temporal correlation [29]. Taking into account the characteristics of short-term subway passenger flow, Zhang Weilin adopted a deep learning-based forecasting model and established a short-term passenger flow prediction model using recurrent neural networks and long short-term memory networks [30]. Qin Yifei addressed the limitations of LSTM, such as the number of neurons, learning efficiency, and iterative complexity, by improving the model through the particle swarm optimization (PSO) algorithm and subsequently constructing the PSO-LSTM model to enhance prediction accuracy [31].

3. Conclusion

Based on the above-mentioned research and analysis of three aspects— the impact of different weather conditions on urban public transportation passenger flow, cloud models, and short-term passenger flow forecasting— the summary is as follows:

(1) Among the external factors affecting urban public transportation passenger flow, weather factors are increasingly valued. Domestic research on the impact of rainfall on urban rail transit passenger flow is limited. Additionally, short-term passenger flow forecasting often does not fully consider rainfall factors. Most studies focus on the influence of rainfall factors on passenger flow at urban rail transit stations. Based on the research of scholars examining the effects of different types of adverse weather and varying times on rail transit passenger flow, future studies can explore the impact of rainfall on rail traffic passenger flow across different daily scenarios.

(2) The cloud model enables uncertain conversion between qualitative concepts and quantitative values. Since the introduction of the cloud model, it has been continuously studied by numerous scholars, leading to its ongoing development. Progressing from the initial one-dimensional model to two-dimensional and multi-dimensional models, the calculation methods for cloud models have been consistently enriched. In transportation, the cloud model is primarily applied to traffic flow prediction, with relatively limited research on passenger flow forecasting.

(3) Various types of prediction methods are underrepresented in the current research. Existing prediction methods each have their own advantages and disadvantages. For instance, while prediction methods based on statistical theory require less computational effort, their prediction accuracy is relatively low in complex situations. Although intelligent theoretical models boast an advantage in data fitting, their principles tend to be more complicated. While non-linear theory methods can reflect the non-linear characteristics of the traffic system, their calculations are relatively complex. However, the current research does not sufficiently address the uncertainty of short-term passenger flow, the influence of rainfall factors, and prediction models with limited historical data.

In the future, a variable factor cloud can be established based on cloud models, taking into consideration rainfall factors or other uncertain variables in predictions. Specifically, the short-term passenger flow of urban rail transit lines can be represented by the three parameters of the cloud, reflecting its uncertainty under various influencing factors. By using the predictive cloud of historical, current, and future passenger flow, the association rules between time and passenger flow clouds can be constructed to perform short-term passenger flow predictions, followed by adjustments as necessary. This short-term dynamic passenger flow prediction model can also achieve accurate predictions of passenger flow under the uncertain factors of rainfall, providing a foundation for efficient operation management of urban rail transit and improving the response efficiency during emergencies.

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