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Research on the Influence of Weather Factors on Urban Rail Transit Passenger Flow

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Abstract. In recent years, cities have been increasingly confronted with frequent and severe extreme weather events, such as heavy rainfall, high temperatures, and strong winds. These extreme weather conditions not only impact urban transportation operations but also directly affect passengers' travel patterns and behaviors. In this context, gaining a deeper understanding of the mechanisms through which weather factors influence urban subway passenger flow becomes crucial. This study aims to investigate the relationship between passenger flow and weather factors, and provide valuable insights for urban rail transit management to enhance proactive decision-making. To achieve this research objective, we first establish a framework for studying the impact of weather on passenger flow. Based on this framework, an analysis is conducted using passenger flow data and weather data from Beijing Metro Line 4. The findings of this study reveal significant effects of different weather factors on subway passenger flow. Increasing severity of weather conditions and higher wind speeds have a negative influence on passenger flow, leading to a decrease in ridership. Conversely, a significant positive correlation is observed between the highest temperature and subway passenger flow, indicating that as the highest temperature rises, the passenger volume also increases.

Keywords: Urban Rail Transit; Passenger Flow; Weather Factors; Regression Analysis; Wind Speed.

1. Introduction

Weather factors have a widespread impact on human activities, influencing adjustments in daily routines such as commuting, attending school, and engaging in tourism, as well as special events like business trips and social gatherings. For instance, Horanont et al. (2013)[1] found that on sunny days, people tend to engage in outdoor activities, while on cloudy or rainy days, they are more inclined towards indoor activities. Moreover, Chen et al. (2020)[2] revealed that essential urban functions such as work-related and educational travel are less disrupted by typhoons, whereas leisure-related travel is more significantly influenced by such events. Within the extensive research on the impact of weather on human activities, the influence of weather on subway passenger flow has been a topic of great interest. Various weather conditions, including rainfall, high temperatures, and wind speed, can significantly affect subway passenger flow.

The relationship between subway passenger flow and weather factors has long been an important research topic in the field of urban transportation. Numerous scholars have conducted investigations and discussions from various perspectives to uncover the mechanisms and trends of weather factors' impact on subway passenger flow. This study aims to contribute to the understanding of the complex system of subway passenger flow by exploring the analysis and prediction models of passenger flow and the influence of weather on subway passenger flow.

The analysis and prediction of subway passenger flow have been widely studied in the academic community. Wang et al. (2022)[3] proposed a subway passenger flow prediction model based on deep learning and spatio-temporal modeling. This model uses convolutional neural networks, long short-term memory networks, and spatio-temporal modeling to forecast subway passenger flow. Li et al. (2021)[4] presented a method for predicting sudden subway passenger flow based on two factors:

time and space. Liu et al. (2018)[5] employed deep learning techniques for subway passenger flow prediction. Moreover, various studies have explored the effects of different weather factors on subway passenger flow, primarily focusing on rainfall and temperature. Najafabadi et al. (2019)[6] found that subway passenger flow is significantly influenced by rainfall, and stations located in commercial areas exhibit lower sensitivity to rainfall on weekdays compared to stations in residential areas. In other words, stations in commercial areas have relatively less impact on passenger volume during weekdays with rainfall. Li et al. (2018)[7] discovered that precipitation-related events have a more significant impact on passenger volume fluctuations compared to temperature-related events. Among these precipitation-related events, snow-related events and larger temperature deviations in winter are identified as the primary causes of passenger volume changes.

However, most of the current studies merely list the effects of weather factors on subway passenger flow without conducting in-depth comprehensive analyses of this complex system. In reality, subway passenger flow is influenced by a complex system composed of various factors, which interact with each other and collectively impact the development of subway passenger flow. Hierarchical regression analysis could serve as an effective tool for systematically analyzing the key factors influencing subway passenger flow. Therefore, this study aims to comprehensively analyze the effects of weather conditions, maximum temperature, and wind speed on subway passenger flow using hierarchical regression, in order to gain a deeper understanding of the mechanisms through which weather affects subway passenger flow. This research holds significant practical implications for the operation and service optimization of subway systems, contributing to improved operational efficiency and passenger experience.

2. Research Methodology

2.1. Research Framework

This study consists of data acquisition and processing, dataset partitioning, exploratory analysis, correlation analysis, hierarchical regression model establishment, and robustness testing. The details are shown in the specific image.

2.2. Data Collection

This study focuses on Beijing Subway Line 4, which consists of 34 subway stations. The research utilizes the upstream passenger flow data from July 2019 and July-August 2020 to quantify the passenger flow. A portion of the data is presented in Table 1.

The weather data for this study is obtained from the website "Weather.com" (https:// www. weather. com) for Beijing City during the months of July 2019, July 2020, and August 2020. The weather data includes variables such as maximum temperature, minimum temperature, weather conditions, and wind direction.

After collecting the passenger flow data and weather data, necessary processing steps are conducted on the raw data. Firstly, the passenger flow and weather data are cleaned and organized to ensure consistency and usability. Subsequently, the subway passenger flow data and weather data are matched in terms of time and integrated based on date and station.

2.3. Variable Selection and Quantification Methods

Subway Passenger Flow Variable: In this study, the total passenger flow for each section within different time periods of a day is calculated by summing up the sectional passenger flows. The total passenger flow reflects the variation in the number of passengers in different sections on a daily basis. An increase in passenger flow can lead to increased congestion in stations and train cars, potentially affecting passengers' travel experience and impacting the subway's operational planning and station scheduling.

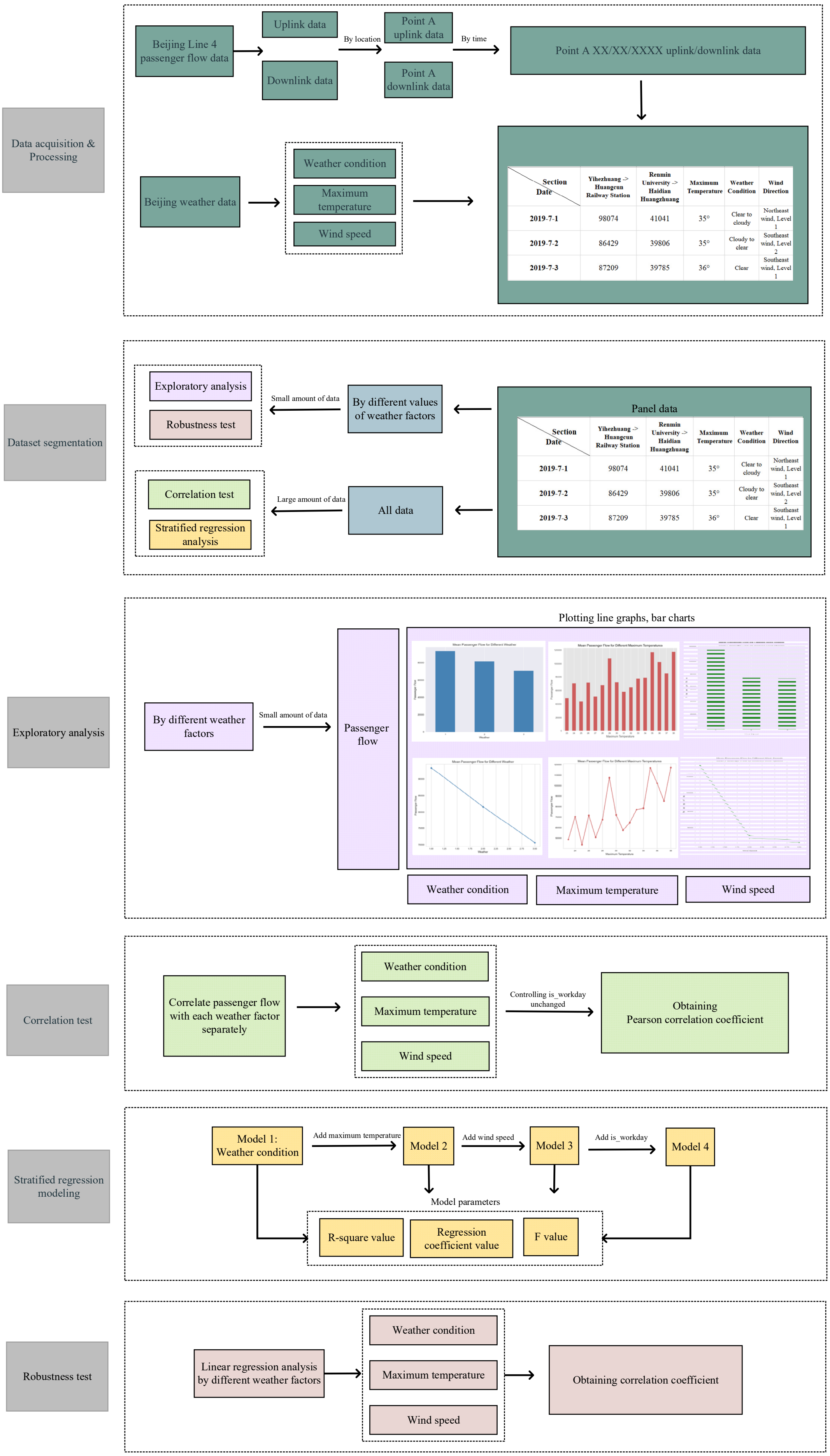

Fig 1. Research framework

Table 1. Selected data on metro patronage

Date	Week	Line	Direction	Zone	Time Period		Passenger Flow
2019-07-01	1	4	Uplink	Zone 1	07:00	07:30	2817
2019-07-01	1	4	Uplink	Zone 1	07:30	08:00	2917
2019-07-01	1	4	Uplink	Zone 1	08:00	08:30	2659
2019-07-01	1	4	Uplink	Zone 1	08:30	09:00	1580
2019-07-01	1	4	Uplink	Zone 1	09:00	09:30	1124
…	…	…	…	…	…	…	…
2019-07-01	1	4	Uplink	Zone 1	12:30	13:00	559
2019-07-01	1	4	Uplink	Zone 1	13:00	13:30	542
2019-07-01	1	4	Uplink	Zone 1	13:30	14:00	492

Weather Variables: The weather variables are categorized into three main categories based on keywords in the weather conditions: "sunny," "cloudy/overcast" without "rain", and "rain." They are assigned values of 1, 2, and 3, respectively. For example, "sunny to cloudy" is assigned a value of 2, and "sunny to light rain" is assigned a value of 3.

Temperature Variable: The impact of daily maximum and minimum temperatures on subway passenger flow is considered to be in the same direction. Therefore, in this study, the daily maximum temperature is chosen to quantify the temperature variable.

Wind Speed Variable: The wind direction data is simplified by removing the directional information, and only the wind speed information is retained for analysis.

2.4. Exploratory Analysis

2.4.1. Relationship between Passenger Flow and Maximum Temperature

The following line graph illustrates the relationship between passenger flow and maximum temperature. The daily maximum temperature is plotted on the horizontal axis, while the corresponding subway passenger flow is represented on the vertical axis. From the graph, it can be observed that as the maximum temperature increases, the passenger flow exhibits some fluctuations but shows an overall upward trend.

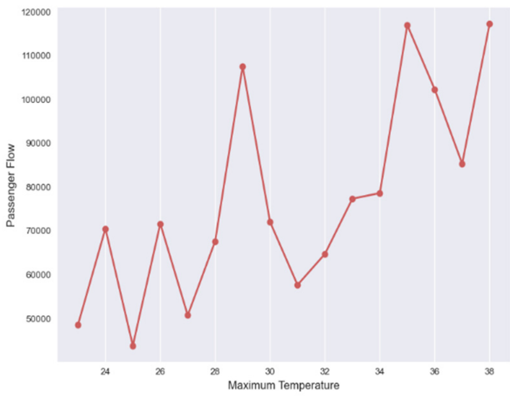

Fig 2. Line graph of passenger flow and maximum temperature

2.4.2. Relationship between Passenger Flow and Weather Conditions

The following bar chart or line graph illustrates the relationship between passenger flow and weather conditions. It can be observed that there is a significant negative correlation between passenger flow and weather conditions: on sunny days, there are more passengers using the subway, while on cloudy or rainy days, the number of passengers decreases, with the strongest impact observed on rainy days.

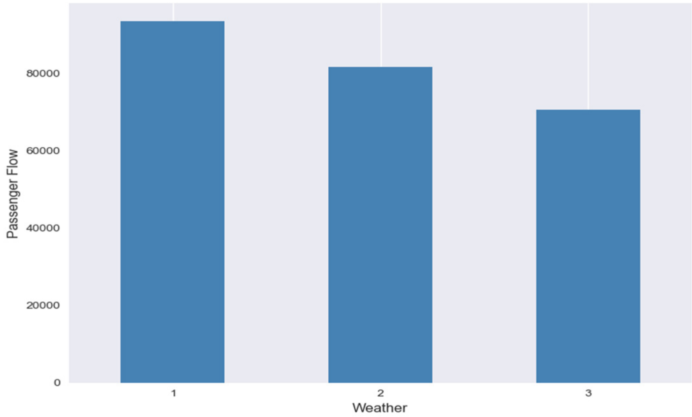

Fig 3. Histogram of passenger flow and weather conditions

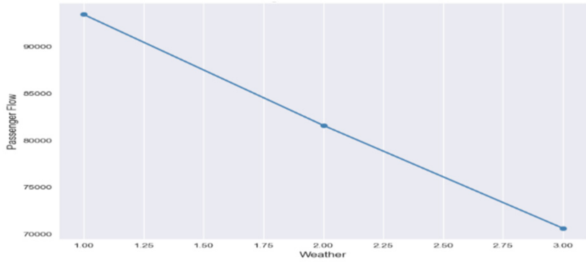

Fig 4. Line graph of passenger flow and weather conditions

2.4.3. Relationship between Passenger Flow and Wind Speed

The following bar chart or line graph illustrates the relationship between passenger flow and wind speed. Based on the preliminary analysis, it can be concluded that there is a significant negative correlation between passenger flow and wind speed.

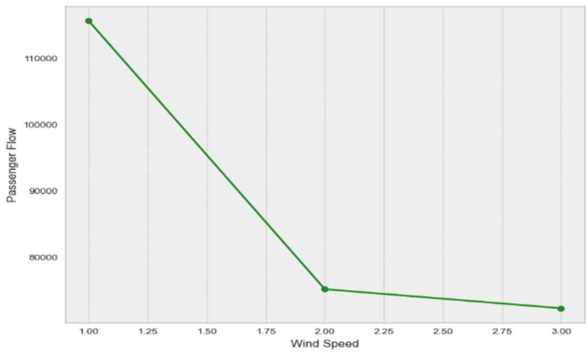

Fig 5. Line graph of passenger flow and wind speed

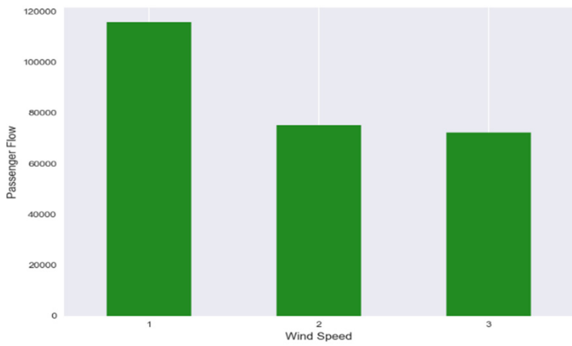

Fig 6. Bar graph of passenger flow and wind speed

2.5. Models

This study employs correlation analysis and stratified regression models to investigate the relationship between subway passenger flow and weather factors.

2.5.1. Correlation Analysis Model

Correlation analysis is a statistical method used to study the relationship between two or more variables. In this study, correlation analysis is utilized to explore the correlation between subway passenger flow and maximum temperature, weather conditions, and wind speed. Specifically, the correlation coefficient is calculated between passenger flow and each weather factor. Commonly used correlation coefficients include Pearson correlation coefficient and Spearman correlation coefficient, which measure linear and non-linear relationships, respectively. Through correlation analysis, we can gain initial insights into the impact and trends of weather factors on subway passenger flow.

2.5.2. Stratified Regression Model

Stratified regression is an extension of multiple regression analysis that allows us to stratify data based on a specific variable and build separate regression models within each stratum. In this study, a stratified regression model is employed to examine whether the relationship between subway passenger flow and weather factors differs across different weather conditions. Specifically, weather conditions are treated as the stratification variable, and regression models are built separately for each weather condition to analyze how the impact of maximum temperature and wind speed on subway passenger flow varies under different weather conditions. Through stratified regression, we can gain a deeper understanding of the role and differences of weather factors on subway passenger flow.

3. Research Results

3.1. Correlation Analysis

To control for variables, this study conducted separate analyses for weekdays and non-weekdays in the correlation analysis.

Non-Weekdays: Correlation analysis is employed to examine the relationships between passenger flow and three weather variables: weather conditions, maximum temperature, and wind speed. The Pearson correlation coefficient is used to measure the strength of the relationships. The specific analysis reveals the following results:

(1)The correlation coefficient between passenger flow and weather conditions is 0.082, and it shows significance at the level of 0.05. This indicates a significant positive correlation between passenger flow and weather conditions.

(2)The correlation coefficient between passenger flow and maximum temperature is 0.213, and it shows significance at the level of 0.01. This indicates a significant positive correlation between passenger flow and maximum temperature.

(3)The correlation coefficient between passenger flow and wind speed is 0.094, and it shows significance at the level of 0.01. This indicates a significant positive correlation between passenger flow and wind speed.

These results indicate that there is a significant positive correlation between passenger flow and weather conditions, maximum temperature, and wind speed on non-weekdays.

Weekdays: In the correlation analysis, the relationships between passenger flow and the three weather variables (weather conditions, maximum temperature, and wind speed) are examined using the Pearson correlation coefficient to measure the strength of the relationships. The specific analysis reveals the following results:

(1)The correlation coefficient between passenger flow and weather conditions is -0.064, and it shows significance at the level of 0.01. This indicates a significant negative correlation between passenger flow and weather conditions.

Table 2. Non-Weekdays: Pearson-Correlation of Passenger Traffic with Weather, Maximum Temperature and Wind Speed Detailed Format

		passenger flow
Weather	correlation coefficient	0.082**
	p	0.014
	sample size	884
Maximum Temperature	correlation coefficient	0.213***
	p	0.000
	sample size	884
Wind Speed	correlation coefficient	0.094***
	p	0.005
	sample size	884
** $p<0.05$ *** $p<0.01$		

(2)The correlation coefficient between passenger flow and maximum temperature is 0.164, and it shows significance at the level of 0.01. This indicates a significant positive correlation between passenger flow and maximum temperature.

(3)The correlation coefficient between passenger flow and wind speed is -0.174, and it shows significance at the level of 0.01. This indicates a significant negative correlation between passenger flow and wind speed.

These results indicate that there is a significant negative correlation between passenger flow and weather conditions and wind speed, while a significant positive correlation exists between passenger flow and maximum temperature on weekdays.

Table 3. Weekdays: Pearson's correlation of patronage with weather, maximum temperature and wind speed - detailed format

		passenger flow
Weather	correlation coefficient	-0.064***
	p	0.002
	sample size	2278
Maximum Temperature	correlation coefficient	0.164***
	p	0.000
	sample size	2278
Wind Speed	correlation coefficient	-0.174***
	p	0.000
	sample size	2278
** $p<0.05$ *** $p<0.01$		

3.2. Model Results

The stratified regression analysis involves four models. In Model 1, the independent variable is weather conditions. Model 2 adds maximum temperature to Model 1, Model 3 includes wind speed in addition to the variables in Model 2, and Model 4 incorporates the variable "is_workday." The dependent variable in all models is passenger flow.

Model 1 - Weather: When using weather conditions as the independent variable and passenger flow as the dependent variable in a linear regression analysis, the results indicate an R-squared value of 0.011. This means that weather conditions can explain 1.1% of the variation in passenger flow. The F-test for the model is significant (F=35.212, p<0.05), indicating that weather conditions have a significant impact on passenger flow. The model equation is: passenger flow = 89881.446 - 6193.766 * weather. The regression coefficient for weather is -6193.766, and it is significant (t=-5.934, p=0.000<0.01), indicating a significant negative impact of weather on passenger flow. In summary, weather conditions have a significant negative impact on passenger flow.

Model 2 - Weather and Maximum Temperature: Building upon Model 1 by adding maximum temperature, the F-value becomes significant (p<0.05), indicating the explanatory power of maximum temperature in the model. Additionally, the R-squared value increases from 0.011 to 0.045, meaning that maximum temperature explains 3.4% of the variation in passenger flow. The regression coefficient for maximum temperature is 3255.227, and it is significant (t=10.581, p=0.000<0.01), indicating a significant positive impact of maximum temperature on passenger flow.

Table 4. Results of stratified regression analyses (n=3162)

	Model 1			Model 2			Model 3			Model 4		
	B	*p*	*β*	*B*	*p*	*β*	*B*	*p*	*β*	*B*	*p*	*β*
Constant	89881.446***	0.000	-	-25081.946**	0.024	-	5062.668	0.692	-	14200.666	0.250	-
Weather	-6193.766 ***	0.000	-0.105	74.865	0.950	0.001	1005.293	0.401	0.017	4552.823***	0.000	0.077
Maximum temperature				3255.227***	0.000	0.212	3132.104 ***	0.000	0.204	2896.841***	0.000	0.189
Wind speed							-14052.924***	0.000	-0.085	-14403.598 ***	0.000	-0.087
is_workday										-30602.401 ***	0.000	-0.267
R^2	0.011			0.045			0.052			0.118		
Adjusted R^2	0.011			0.044			0.051			0.117		
F value	$F(1,3160)=35.212$, $p=0.000$			$F(2,3159)=74.208, p=0.000$			$F(3,3158)=57.301, p=0.000$			$F(4,3157)=105.556, p=0.000$		
$\triangle R^2$	0.011			0.034			0.007			0.066		
$\triangle$F value	$F(1,3160)=35.212$, $p=0.000$			$F(1,3159)=111.968, p=0.000$			$F(1,3158)=22.477, p=0.000$			$F(1,3157)=237.451, p=0.000$		
$^{**}p<0.05$ $^{***}p<0.01$												

Model 3 - Weather, Maximum Temperature, and Wind Speed: Adding wind speed to Model 2 results in a significant change in the F-value (p<0.05), indicating the explanatory significance of wind speed in the model. The R-squared value increases from 0.045 to 0.052, indicating that wind speed explains an additional 0.7% of the variation in passenger flow. The regression coefficient for wind speed is -14052.924, and it is significant (t=-4.741, p=0.000<0.01), indicating a significant negative impact of wind speed on passenger flow.

Model 4 - Weather, Maximum Temperature, Wind Speed, and Is_Workday: Adding the variable "is_workday" to Model 3 leads to a significant change in the F-value (p<0.05), indicating the explanatory significance of "is_workday" in the model. The R-squared value increases from 0.052 to 0.118, indicating that "is_workday" explains an additional 6.6% of the variation in passenger flow. The regression coefficient for "is_workday" is -30602.401, and it is significant (t=-15.409, p=0.000<0.01), indicating a significant negative impact of "is_workday" on passenger flow.

3.3. Robustness Test

To ensure the reliability of the results, robustness tests are conducted using linear regression models after grouping passenger flow based on different values of maximum temperature, weather conditions, and wind speed.

3.3.1. Passenger Flow and Weather

Using weather conditions as the independent variable and passenger flow as the dependent variable in a linear regression analysis, the model equation is: passenger flow = 104686.074 - 11396.272 * weather. The R-squared value for the model is 1.000, indicating that weather conditions can explain 100.0% of the variation in passenger flow. The F-test for the model is significant (F=2123.840, p=0.014<0.05), indicating that weather conditions have a significant impact on passenger flow. The regression coefficient for weather is -11396.272 (t=-46.085, p=0.014<0.05), indicating a significant negative impact of weather conditions on passenger flow. In summary, weather conditions have a significant negative impact on passenger flow. Therefore, the robustness test confirms the relationship between passenger flow and weather conditions.

3.3.2. Passenger Flow and Maximum Temperature

Table 5. Results of linear regression analysis between passenger flow and maximum temperature (n=16)

	Unstandardised Coefficient		Standardised Coefficient	t	p	Covariance Diagnostics	
	B	Standard Error	$Beta$			VIF	Tolerance
Constant	-29485.506	28357.044	-	-1.040	0.316	-	-
Maximum Temperature	3492.616	919.299	0.712	3.799	0.002***	1.000	1.000
R^2	0.508						
Adjustment R^2	0.472						
F	$F(1,14)=14.434, p=0.002$						
D-W value	2.152						
** $p<0.05$ *** $p<0.01$							

Using maximum temperature as the independent variable and average passenger flow as the dependent variable in a linear regression analysis, the model equation is: average passenger flow = -29485.506 + 3492.616 * maximum temperature. The R-squared value for the model is 0.508, indicating that maximum temperature can explain 50.8% of the variation in average passenger flow. The F-test for the model is significant (F=14.434, p=0.002<0.05), indicating that maximum temperature has a significant impact on average passenger flow. The regression coefficient for maximum temperature is 3492.616 (t=3.799, p=0.002<0.01), indicating a significant positive impact of maximum temperature on average passenger flow. In summary, maximum temperature has a significant positive impact on average passenger flow. Therefore, the robustness test confirms the relationship between passenger flow and maximum temperature.

3.3.3. Passenger Flow and Wind Speed

Using wind speed as the independent variable and average passenger flow as the dependent variable in a linear regression analysis, the model equation is: average passenger flow = 131042.747 - 21641.830 * wind speed. The R-squared value for the model is 0.799, indicating that wind speed can explain 79.9% of the variation in average passenger flow. However, when conducting the F-test for the model, it is found that the model does not pass the F-test (F=3.987, p=0.296>0.05), indicating that wind speed does not have a significant impact on average passenger flow. Therefore, it is not possible to analyze the specific relationship between the independent variable and the dependent variable. Due to the lack of significant influence from wind speed and considering factors such as the limited range of wind speeds in the data used in this study (with the maximum wind speed in Beijing being only 3), the relationship between passenger flow and wind speed did not pass the robustness test.

Table 6. Results of linear regression analysis between passenger flow and wind speed (n=3)

	Unstandardised coefficient		Standardised coefficient	*t*	*p*	Covariance Diagnostics	
	B	Standard error	*Beta*			*B*	Standard error
a constant (math.)	131042.747	23413.760	-	5.597	0.113	-	-
Wind Speed	-21641.830	10838.465	-0.894	-1.997	0.296	1.000	1.000
R^2	0.799						
Adjustment R^2	0.599						
F	$F(1,1)=3.987, p=0.296$						
D-W value	3.000						
$^{**}p<0.05$ $^{***}p<0.01$							

3.4. Result Analysis

3.4.1. Interpretation of Results

The model analysis results indicate that different weather factors have a significant impact on subway passenger flow. Weather conditions have a significant negative impact on passenger flow, indicating that as the severity of the weather worsens, the passenger flow decreases. This could be due to a decrease in the number of people traveling during inclement weather, resulting in a decrease in subway passenger flow.

There is a significant positive relationship between maximum temperature and passenger flow. This means that as the maximum temperature increases, the subway passenger flow also increases. This could be because favorable temperatures encourage more people to choose the subway for their travels, regardless of the weather.

Wind speed has a negative impact on passenger flow, indicating that higher wind speeds may lead to a decrease in subway passenger flow. The possible reason is that high wind speeds result in a poor travel experience, and passengers may switch to other modes of transportation.

3.4.2. Weather Forecasting

Based on our model analysis, we can use weather conditions, maximum temperature, and wind speed from weather forecast data to predict passenger flow under different weather conditions. This will provide important reference for subway operations and management. When the weather forecast indicates the possibility of inclement weather, operators can take corresponding measures, such as increasing train frequency and capacity, to provide better service and accommodate fluctuations in passenger flow.

3.4.3. Urban Planning and Traffic Management

The research results of this study have practical application value for urban planning, traffic flow optimization, and traffic management. In response to the impact of different weather factors on passenger flow, urban planners and traffic managers can take a series of measures to optimize subway operations and passenger travel experience.

When designing subway station layouts, weather factors should be taken into account. For example, in areas that may be affected by rainfall, shelters or rain coverings can be added, or rainproof passageways can be created. Additionally, opportunities should be seized during seasons with suitable temperatures to attract more passengers to use the subway, such as offering incentives or organizing events.

Furthermore, in terms of traffic management, when extreme weather events that may affect passenger flow occur, traffic management departments can guide passengers to choose appropriate modes of transportation and alleviate traffic congestion through real-time scheduling and information dissemination.

4. Conclusion

4.1. Summaries

The results of this study demonstrate that different weather factors have a significant impact on subway passenger flow. Increasing severity of weather conditions and higher wind speeds have a negative impact on passenger flow, leading to a decrease. The study also reveals a significant positive relationship between maximum temperature and subway passenger flow, indicating that passenger flow increases with higher maximum temperatures.

The highlight of this study lies in the use of a hierarchical regression model to comprehensively consider the impact of multiple weather factors on passenger flow, rather than solely analyzing individual factors. This integrated research approach better reflects the complex mechanisms through which weather influences subway passenger flow.

4.2. Theoretical Implications

This study makes several important theoretical contributions to understanding the impact of weather on passenger flow. Firstly, it addresses the theoretical gap regarding the influence of weather factors in the transportation field. While previous studies have touched upon weather factors, they often lack a comprehensive analysis of multiple factors. In contrast, our study examines weather conditions, temperature, wind speed, and other factors from various perspectives, filling this research gap.

Secondly, this study emphasizes the positive relationship between maximum temperature and subway passenger flow. During hot seasons, the maximum temperature significantly affects passengers' travel decisions and modes of transportation. By incorporating the maximum temperature into the analysis model, we can better account for the influence of temperature in weather on subway passenger flow.

Additionally, this study uniquely considers wind speed as a factor when exploring the impact of meteorological factors on subway passenger flow. Previous research often overlooks the influence of wind speed, and our study fills this research gap. The results indicate that wind speed also has a certain impact on subway passenger flow, particularly in cases of higher wind speeds. Severe winds may inconvenience pedestrians, increasing the likelihood of passengers choosing the subway as their mode of transportation.

4.3. Managerial Implications

Firstly, this study clearly indicates that weather conditions have a negative impact on subway passenger flow. As the severity of weather worsens, there is a noticeable decrease in subway passenger flow. This conclusion provides important guidance for managers. They need to pay attention to weather conditions and conduct equipment maintenance and repairs during inclement weather to ensure the stable operation of the system. Additionally, during favorable weather conditions, managers can increase the frequency of subway trains to better balance the supply and demand of subway passenger flow.

Secondly, from a competitive market perspective, when weather conditions are good and temperatures are favorable, subway systems experience higher passenger flow. During such times, ride-hailing services and taxis can offer promotional activities to encourage travelers to choose alternative modes of transportation other than the subway, thereby alleviating the pressure on subway passenger flow. Conversely, when weather conditions are unfavorable, increasing the supply of taxis and ride-hailing services can meet the high demand for rapid transportation.

Lastly, based on the relationship between subway passenger flow and weather factors highlighted in this study, the following management suggestions can be provided to subway operators and relevant decision-makers: Firstly, flexible operation plans. According to a consumer trends report released by Ericsson in February 2023, about 68% of respondents prioritize energy costs over time efficiency. Subway operators can develop more flexible operation plans. In unfavorable weather conditions, they can increase the frequency of subway trains and provide more travel options to meet passenger demand. Secondly, emergency response for critical events. Faced with record-breaking high temperatures, wildfires, and heavy rainfall and floods in the past two years, subway operators should develop emergency response plans. Strengthening cooperation with relevant departments ensures that subway operations can make timely adjustments in the event of disasters, ensuring the safety of passengers.

4.4. Limitations and Future Study

Firstly, the sample of this study is limited to three months of data from Beijing Subway Line 4 in 2019-2020, primarily during the summer vacation period, which may lack generalizability and representativeness. In the future, the research sample can be expanded to include more subway lines and a longer time period, covering data from different seasons and weather conditions. This would increase the universality and representativeness of the study and provide a more comprehensive analysis of the impact of weather on subway passenger flow.

Secondly, in terms of quantitative methods, this study divides the time dimension into daily intervals, which may have limitations in terms of accuracy and precision. Future research can consider using more refined granular time intervals, such as hourly or minute-based intervals, to capture the changing relationship between weather and passenger flow more precisely.

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