Research on the Influence of Rainfall Weather on Urban Road Characteristics

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Abstract. In order to ensure the high-quality operation of urban traffic, the impact of rainfall on urban road characteristics was studied. Taking Zhengzhou as an example, the traffic volume, headway time and vehicle start loss time under different rainfall were counted. By studying the mechanism of the basic capacity and actual capacity of roads affected by rainfall, the changes in the degree of impact of rainfall on roads and other traffic environments are determined.

1. Introduction
Urban traffic is a basic part of the normal operation of a city. When severe weather such as rain and snow occur, the road is directly affected by rain and snow, which will greatly reduce the physical performance of the road, and the visibility will also be reduced to varying degrees, which will reduce the driver’s ability to perceive and judge the environment and drive the vehicle safely. The speed is reduced, resulting in a decline in its traffic capacity, making citizens have a poor travel experience. At this time, the public transportation burden rate will increase significantly, the passenger flow of buses and subways will increase significantly, and the degree of congestion will increase during the peak period, and even lead to the paralysis of the transportation system, making it more difficult to control traffic. Therefore, in order to deal with the relative shortage of infrastructure resources such as road resources, increase the influence mechanism of bad weather on urban road capacity, and put forward scientific and reasonable measures for traffic control when bad weather occurs. It is of great practical significance to ensure the high quality operation and development of urban traffic.

In their research, foreign scientific researchers have found that the actual traffic capacity of roads is closely related to weather conditions, especially bad weather will greatly reduce the traffic capacity of roads. Therefore, it is necessary to adjust and standardize the urban traffic operation mode and management policies and systems when severe weather occurs. Agarwal conducted statistical analysis on traffic flow data of urban roads in the western United States under the influence of severe weather such as rainfall, snowfall, fog, and wind. The results showed that the capacity of urban roads decreased by 10%-17% in rainy weather; the capacity of urban roads decreased by 19%-27% in snowy weather. HCM2000 pointed out that unlike in fine weather, when bad weather occurs, the deterioration of the traffic environment reduces the safe driving speed of traffic flow, which in turn reduces the traffic capacity of the road. The manual points out that wet roads will not cause a decrease in the speed of the vehicle, but when the visibility decreases, the vehicle must reduce the speed to ensure safe passage. Therefore, light rain basically does not affect the road capacity, but when the visibility changes caused by heavy rain, the road capacity will be reduced by 10.7%-17.7%. Researcher Smith conducted a
statistical analysis of traffic flow data on major roads in various US cities under different weather conditions. After research, it is found that the reduction ratio of road capacity is about 7% during light rain and over 24% during heavy rain, but does not exceed 32% [1]. Japanese researcher Chung et al. analyzed the traffic flow data of Tokyo Expressway from 1998 to 2004, and obtained the mechanism of the impact of rainfall on traffic volume. The results showed that when the rainfall from Monday to Friday increased from 1mm to 30mm, Will cause the traffic volume to decrease by about 2%-4%, and the impact on weekends will be even greater, with a decrease of 4%-14% [2]. Guoliang Qiao [3] of Beijing University of Technology applied video detectors. Microwave detectors counted the specific traffic flow data of some expressways and main roads in Beijing under the conditions of blocked rainfall and snow, and analyzed them. The research results show that the specific impact of severe weather on the capacity and traffic flow speed of the road section has a strong correlation with the perfection of the road section’s transportation infrastructure. Researcher Zhongliang Yang [4] conducted a large number of integrated statistical analysis on my country’s traffic flow data and meteorological data. Based on the classification of different severe weather levels, he conducted a quantitative analysis of the road capacity under different rainfall levels, and obtained different results. The law of road capacity changes under rainfall conditions.

From the above research results, it can be seen that the research focus of domestic and foreign researchers is mainly on the changes in vehicle speed caused by different severe weather, and the vehicle speed is obviously affected by severe weather such as rainfall. Therefore, in this article, we mainly study the reduction of vehicle speed under different rainfall conditions to reflect the specific impact of urban road capacity in severe weather.

2. Impact analysis of urban road characteristics under rainy weather

2.1. Definition and classification of rainfall weather

Rainfall is a common natural phenomenon in our daily life. Its formation mechanism is: the water on the earth evaporates and becomes water vapor floating in the air. At high altitude, the water vapor will condense into small water droplets and gather into clouds. It further condenses into water droplets and merges with each other to increase in volume. When the air cannot bear its gravity, it falls from the sky to the ground and becomes common rainwater. The division of rainfall intensity is related to the rainfall per unit time, while rainfall is related to surface temperature and evaporation. For this, all countries in the world have their own corresponding indicators for the classification of rainfall levels.

My country's meteorological department has also formulated its own standards for the classification of rainfall: a 12-hour or 24-hour unit is used to classify rainfall according to the rainfall in this time period. The rainfall statistics are usually based on mm (millimeters) as the unit, and take one decimal place. In this article, the rainfall level is divided into three categories: light rain, moderate rain and heavy rain. The classification of rainfall levels is shown in Table 1:

| Classification   | Rainfall in 12 hours (mm) | Rainfall in 24 hours (mm) |
|------------------|---------------------------|---------------------------|
| Light rain       | 0.5                       | <10.0                     |
| Moderate rain    | 5.0 - 10.0                | 10.0 - 25.0               |
| Heavy rain       | 10.0 - 30.0               | 25 - 49.9                 |

2.2. Analysis of the impact of rainfall weather on the performance of urban road sections

2.2.1. Analysis of changes in road properties under rainfall conditions

The actual capacity of the road is affected by many factors, among which the adhesion coefficient of the road has a significant influence on the capacity and safety of the road. In rainy weather, it is agreed that the actual capacity of road sections under different rainfall conditions, different road sections under the
same rainfall conditions and road surfaces of different materials have significant changes. In actual analysis, the degree of road condition change under different conditions is quantified as the road adhesion coefficient for analysis. This article mainly analyzes the road adhesion coefficient of urban road asphalt pavement and cement pavement under different rainfall.

During the driving of the vehicle, the friction between the tire and the road surface directly affects the acceleration capability of the vehicle, which in turn affects the actual road capacity. No matter what state the road is in during operation, it will affect the acceleration ability of the vehicle. The adhesion coefficients of different material road surfaces in normal dry conditions are shown in Table 2:

Table 2  Pavement Adhesion Coefficient Table

| Type of pavement         | Adhesion coefficient |
|--------------------------|----------------------|
| Cement concrete pavement | 0.70-1.0             |
| Asphalt concrete pavement| 0.75-1.0             |

The adhesion coefficient of the road surface is related to the dryness of the road and the road material, and has nothing to do with the state of the attachments in contact. According to the data analysis, the adhesion coefficient reduction coefficients of cement concrete pavement and asphalt concrete under rainy weather conditions are 29%-35% and 37%-43%, respectively. In the past research experience, it is known that rainfall will largely cause accumulation of water on the road surface, forming a water film of different thickness, and the thickness of the water film will reduce the adhesion coefficient of the road surface to varying degrees. When the vehicle speed is different, the water film will have a significant impact on the road adhesion coefficient. The specific adhesion coefficient is shown in Table 3:

Table 3  Road Adhesion Coefficient Under Different Water Film Thickness And Speed

| Water film thickness (mm) | 30  | 40  | 50  | 60  |
|---------------------------|-----|-----|-----|-----|
| 0.3                       | 0.823| 0.742| 0.679| 0.535|
| 0.6                       | 0.821| 0.724| 0.660| 0.496|
| 0.9                       | 0.812| 0.711| 0.598| 0.458|
| 1.2                       | 0.801| 0.702| 0.576| 0.417|
| 1.5                       | 0.707| 0.686| 0.541| 0.382|

There is a certain relationship between the thickness of the water film and the intensity of rainfall, which in turn affects the running speed of vehicles in a rainfall environment. In this regard, some foreign researchers have conducted research. Russam proposed a calculation formula for the thickness of the water film on the road surface as shown in (1):

\[ d = 0.017 \times (l \times i)^{0.47} \times s^{-0.2} \]  

(1)

Among them: \( d \): water film thickness (mm); \( l \): drainage length (m); \( i \): rainfall intensity (mm/12h); \( s \): road slope.

Different dry conditions of the road surface, different materials of the road surface, and different vehicle speeds have different degrees of influence on the adhesion of the road. Under different dry conditions of the pavement, the adhesion coefficient of asphalt and concrete pavement during sliding and peak values are shown in Table 4:

Table 4  Road Adhesion Coefficient Under Different Conditions

| Road condition              | Adhesion coefficient (sliding) | Adhesion coefficient (peak value) |
|-----------------------------|--------------------------------|----------------------------------|
| Normal road                 | 0.75                           | 0.8-0.9                          |
| Non-dry concrete pavement   | 0.7                            | 0.8                              |
| Non-drying asphalt pavement | 0.45-0.6                       | 0.5-0.7                          |

To sum up the analysis: in different rainfall environments, the actual adhesion coefficient of the road has a certain degree of decline compared with the normal dry road. The specific degree of decline is related to the thickness of the road water film formed under the combined influence of rainfall and road drainage capacity.
2.2.2. Analysis of the impact of rainfall weather on the capacity of road sections

1) Basic capacity

The basic capacity has a clear definition: when the traffic environment is in an ideal state and the road infrastructure is in good condition, the maximum traffic volume that a single lane or unit road section can pass in a unit time. As shown in formula (2):

\[ C_{j} = \frac{3600}{t_0} = \frac{3600v}{3.6l_0} = \frac{1000v}{l_0} \]  

\( v \): driving speed (km/h); \( t_0 \): average headway (s). The time interval is shown in formula (3):

\[ l_0 = l_1 + l_2 + l_3 + l_4 = \frac{v}{v_0} + \frac{v^2}{2a} + l_3 + l_4 \]  

\( l_0 \): Minimum headway (m); \( t_0 \): Driver response time, about 1.2s can be taken; \( l_1 \): Safe driving distance (m); \( l_2 \): Brake distance (m); \( l_3 \): Reaction time vehicle driving distance (m); \( l_4 \): Average vehicle Length (m).

2) Actual capacity

The actual capacity is usually calculated on the basis of a single lane, and the theoretical capacity needs to be revised in the next step. The main correction coefficients that need to be considered are four aspects: intersection, bicycle influence, number of lanes, and lane width. The mathematical model is shown in formula (4):

\[ C_s = C_0 \cdot f_r \cdot f_n \cdot f_c \cdot f_i \]  

\( C_s \): Actual capacity of road section; \( f_r \): Bicycle influence correction factor; \( f_n \): Lane correction factor; \( f_c \): Lane width correction factor; \( f_i \): Intersection influence correction factor.

The specific correction coefficient indicators are shown in Table 5, Table 6, and Table 7:

| Road section condition | Machine non-separation | Two boards | Machine non-mixed |
|------------------------|------------------------|------------|------------------|
| Bicycle correction factor \( \gamma \) | 1 | 0.8 | 0.7 |

| Width (m) | 2.5 | 3 | 3.5 | 4 | 4.5 |
|-----------|-----|---|-----|---|-----|
| Correction factor \( \eta \) | 0.5 | 0.75 | 1 | 1.12 | 1.2 |

| Number of lanes | 1 | 2 | 3 | 4 |
|-----------------|---|---|---|---|
| Correction factor \( \eta \) | 1 | 1.87 | 2.60 | 3.20 |

From the above analysis of influencing factors, it can be seen that the actual capacity and driving speed of the road are related to rainfall. With the increase of rainfall intensity, the capacity and driving speed of the road will change to varying degrees. Rainy weather will cause the road adhesion coefficient to decrease, and the braking performance of vehicles will also decrease, leading to an increase in braking distance; when rainy weather occurs, changes in environmental factors will affect the traffic participants’ traffic psychology, which will inevitably be In some sections of the road, electric bicycles and motor vehicles are mixed, causing chaos in the traffic flow and reducing the actual traffic capacity of the road. At the same time, rainfall causes the visibility of the traffic environment to decrease, and the front windshield and rearview mirror of the vehicle will accumulate water droplets, making the driver's vision Blur, reduce the recognition of obstacles around the driving vehicle. In order to ensure the safety of
driving operation, the driver must reduce the speed of the vehicle, so that the actual traffic capacity of urban road sections in rainy weather is lower than normal weather.

3. Analysis of the impact of rainfall on the traffic capacity of signalized intersections

Signal-controlled intersections are the main connecting part of the urban road traffic network, and their traffic capacity determines or restricts the traffic capacity of the entire urban road network to a high degree. Therefore, the traffic capacity of signal-controlled intersections is also the bottleneck of urban road traffic capacity improvement. At the same time, the traffic flow at road intersections is relatively complicated, and a large part of traffic safety accidents occur at signalized intersections. Therefore, the traffic carrying capacity of signalized intersections largely reflects the reliability and resistance of urban road networks.

In a rainy environment, the visibility of the traffic environment and the ground adhesion coefficient will be reduced to varying degrees, resulting in a decrease in ground friction, which will affect the driver’s perception and response during driving to a certain extent, making it rainy weather. The characteristics of traffic flow are very different from those in fine weather. For example: At an urban signalized intersection, due to the presence of rainfall, vehicle start-up loss and delay increase, and the increase in headway will reduce the saturation flow rate, causing the traffic capacity of the intersection to decrease; at the same time, due to the complex traffic environment, the intersection probability of local security incidents will also increase significantly. From this point of view, the traffic safety management measures and basic transportation facilities under normal weather will not be able to meet the traffic demand in environments such as rainfall. When encountering severe weather such as rainfall, the traffic operation characteristics of urban signal intersections will change. Traffic is prone to chaos or even congestion, which greatly reduces the level of urban traffic service. Therefore, the problem of the influence mechanism of rainfall on the traffic capacity of signal-controlled intersections needs to be studied and solved urgently.

3.1. Research on the influence of rain weather on headway

The headway is the time difference between the front and rear cars passing a certain point on the road in the same lane and the same flow direction. It is generally expressed as the time difference between the front or rear of the two cars passing through the point. In this paper, the headway is determined by the time interval between two consecutive cars in the same lane passing the stop line at the signal intersection at the rear of the vehicle. When vehicles pass the signal control intersection, when the signal light is red, the vehicles need to wait in line. When the green light is on, the vehicles start to pass through the intersection sequentially. Take the time difference between the first vehicle passing the stop line and the second vehicle passing the stop line when the green light is on as the headway of the first vehicle, and so on. In the study, it was found that there are differences in the headway of vehicles with different steering. Therefore, during the study, the vehicles with different steering were classified, collected and analyzed.

In this paper, the signal intersection of Wenhua Road and Dongfeng Road and the signal intersection of Dongfeng Road and Information College Road in Zhengzhou City are taken as examples for data collection and analysis. The study found that the headway of the third vehicle passing at the signalized intersection starts Tend to be stable. In this paper, starting from the third vehicle, the saturated traffic time at the intersection is recorded.
Figure 1 Intersection of Dongfeng Road and Wenhua Road (map)

Figure 2 Intersection of Dongfeng Road and Wenhua Road (on the spot)

Figure 3 Intersection of Dongfeng Road and Information College Road (map)

Figure 4 Intersection of Dongfeng Road and Information College Road (on the spot)
The specific survey statistics are shown in Table 8:

| Different lanes | Sunny day | Light rain | Moderate rain | Heavy rain | Sunny day | Light rain | Moderate rain | Heavy rain |
|-----------------|-----------|------------|---------------|------------|-----------|------------|---------------|------------|
| straight        | 2.094     | 2.220      | 2.913         | 2.995      | 1708      | 1682       | 1440          | 1241       |
| Turn left       | 2.138     | 2.413      | 3.205         | 3.327      | 1639      | 1572       | 1338          | 1181       |
| Turn right      | 2.315     | 2.561      | 3.331         | 3.851      | 1501      | 1494       | 1286          | 1241       |

From the statistical data in the table, it can be seen that the headway saturation time is larger in rainy weather than in fine weather. At the same time, as the rainfall intensity increases, the headway saturation time also increases; compared with rainy weather, In fine weather, the saturated flow rate decreases, and with the increase of rainfall intensity, the saturated flow rate gradually decreases. It can be analyzed that the influence mechanism of rainfall on the traffic capacity of signal-controlled intersections is: the increase of rainfall intensity causes changes in the traffic environment, reduced visibility, reflections when there is water on the ground, and drivers' sensitivity to surrounding traffic information. The decline in traffic safety will reduce traffic safety. In order to ensure the safety of traffic operation, the speed of vehicles must be reduced, which in turn causes a decline in the capacity of signalized intersections.

3.2. Research on the influence of rainfall weather on the start-up loss time

At a signalized intersection, when the green light comes on, the vehicles waiting to pass start to start and accelerate through the intersection. It is difficult for the traffic flow at the intersection to reach saturation during the beginning of the traffic period. Especially in rainy weather, the impact of changes in the traffic environment on the driver, vehicle performance and road performance will cause the vehicle start-up loss time to change. In this article, the vehicle start-up loss time is defined as the amount of traffic time lost between when the green light signal is turned on and before the traffic flow reaches saturation. Its mathematical model is shown in formula (5):

\[ l_i = \sum_{i=1}^{n} h_i - n \cdot h_i \]  

\( l_i \): starting loss time(s);  
\( i \): vehicle queue position;  
\( n \): number of vehicles that have not reached the saturated headway;  
\( h_i \): the headway of the first vehicle that has not reached the saturated headway(s);  
\( h_i \): the saturated headway(s).

Regarding the impact of rainfall on signalized intersections, we still take the statistical data of the intersection of Dongfeng Road and Wenhua Road and the intersection of Wenhua Road and Dongfeng Road as examples. The survey results are shown in Table 9 and Table 10:

| Vehicle sequence | Light rain | Moderate rain | Heavy rain |
|------------------|------------|---------------|------------|
| Car 1            | 3.33       | 4.03          | 4.81       |
| Car 2            | 2.97       | 3.82          | 4.33       |
| Car 3            | 2.42       | 3.11          | 4.01       |
| Car 4            | 2.23       | 2.67          | 3.24       |
| Car 5            | 2.12       | 2.69          | 3.21       |
### Table 1.10 Vehicle Start-up Loss Time Under Different Weather Conditions

| Vehicle sequence | 1  | 2  | 3  | 4  | 5  |
|------------------|----|----|----|----|----|
| Normal weather   | 0.94 | 1.63 | 1.77 | 1.74 | 1.54 |
| Light rain       | 1.11 | 1.86 | 2.06 | 2.07 | 1.97 |
| Moderate rain    | 1.12 | 2.02 | 2.22 | 2.08 | 1.755 |
| Heavy rain       | 1.82 | 3.15 | 4.17 | 4.41 | 4.63 |

From the above statistical results, it can be seen that as the severe weather conditions intensify, the start-up loss time of vehicles shows an increasing trend. The vehicle loss time under the same weather and its sequence position show a certain law: when the weather conditions are normal weather, light rain, moderate rain, it can be approximated that the start loss time of the first three vehicles is gradually increasing, and the third The vehicle start loss time after a vehicle is gradually decreasing; under heavy rain conditions, the vehicle start loss time shows an increasing trend.

From this analysis, it can be seen that the specific influence mechanism of severe weather with different rainfall intensities on the capacity of urban roads is:

1. Under environments with different rainfall intensities, the nature of road infrastructure will change accordingly, and the actual adhesion coefficient of the road surface will decrease to a certain extent compared with that of a normal dry road. The specific decrease will increase with the increase in rainfall and the water film on the road surface. The increase in thickness increases.

2. Rain will also reduce the road adhesion coefficient, the braking performance of the vehicle will decrease, the braking distance will increase, and the safe driving speed of the vehicle will decrease, resulting in a decrease in the actual traffic capacity of the road. The traffic capacity of signal-controlled intersections will decrease when the traffic environment is bad, which is mainly reflected in the saturation time of vehicles passing through the intersection and the start-up loss time of vehicles increasing with the increase of rainfall level.

### 4. Summary

This paper classifies the rainfall level according to the difference of rainfall. Based on this, statistics are made on the traffic volume, headway time and vehicle start-up loss time of some road sections and signal-controlled intersections in Zhengzhou under different weather. Based on this analysis, the basic capacity and actual capacity of roads are affected by rainfall, and the changes in the degree of impact of rainfall on roads and other traffic environments are determined.

### References

[1] Smith B L, Byrne K G, Copperman R B, et al. An investigation into the impact of rainfall on freeway traffic flow [C] // 83rd annual meeting of the Transportation Research Board, Washington D C. 2004.

[2] Chung E, Ohtani O, Warita H, et al. Effect of rain on travel demand and traffic accidents[C]// Intelligent Transportation Systems. 2005.

[3] Guoliang Qiao. Research on characteristic parameters of traffic flow in urban road sections under adverse weather conditions[D]. Beijing University of Technology, 2014.

[4] Zhongliang Yang, Lin Yu, Xiao Gao. Study on the capacity of urban expressways under severe weather conditions[J]. Traffic Information and Safety, 2010, (01): 75-78.