Research on Reasonable Spacing of Adjacent Highway Plane Intersections

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Abstract. In China's relevant specifications, the minimum spacing of plane intersections is simply defined according to the grade of highway, and the design speed of intersections and the influence of intersection geometry are not considered. In this paper, the traffic flow characteristics of road sections, the influencing factors of the intersection of road intersections and the sections between plane intersections are divided into entry points. The intersection functional zone and the length of smooth running zone are theoretically analysed. According to the influence of factors, the length of each segment is calculated separately, and the reasonable spacing index of the intersection is proposed.

1. Introduction
The spacing of the intersections is often based on the norms [1] and the experience of the designers, with great subjectivity and randomness. When the interval between adjacent plane intersections is too small, it will cause serious interference to intersection traffic and increase traffic safety hazards [2]. Foreign studies on the intersection of plane intersections are mostly regression analysis of road safety impact analysis, spacing and accident rate, mostly qualitative analysis or relying on a large number of accident data. Since the traffic accident data in China cannot be easily obtained, and the road conditions and traffic environment at home and abroad are quite different, it is not appropriate to apply foreign related research directly to the Chinese highway system. At present, Chinese research focuses on traffic simulation, and proposes a plane intersection spacing model, but few studies the relationship between the length and spacing of intersections, which can't reflect the influence of the length of the structure on traffic operation [3].

The intersection entrance and exit lanes of the intersection have the functional area before and after the intersection, and the length of the front and rear functional areas is calculated. The reasonable spacing formula of the intersection based on the length of the functional area before and after the intersection is given, which is beneficial to improve the standardization of the intersection setting.

2. Analysis of the composition and influence factors of the spacing of plane intersections

2.1. Overview of the spacing of plane intersections
According to the function, grade, traffic volume, etc. of the intersecting road, the plane intersection can adopt three different traffic management modes: main road priority crossing, no priority crossing or signal crossing. This paper only deals with cross-type intersections with no signal main path priority control crossover. The reasonable spacing of the main road priority control intersections must meet the requirements of safe driving, stable traffic flow, corresponding design service level and safety facilities.
The reasonable spacing between highway intersections studied in this paper refers to the total distance of the vehicle from the physical area of a plane intersection to the normal driving of the next intersection.

2.2. Analysis of influencing factors.
Vehicles often cannot pass under ideal roads and environmental conditions, and will be affected by many factors, resulting in reduced road capacity. The main factors affecting are: number of lanes, lane width and road surface humidity conditions, design speed, traffic composition, and lateral direction. Changes in headroom and overall characteristics of the driver, etc., will cause changes in the speed-flow rate-density relationship.

Traffic flow density is an important factor in determining whether the spacing of adjacent intersections is reasonable. The unreasonable spacing of the intersections will result in uneven distribution of traffic on the road sections, and the traffic burden at the intersections of adjacent road sections will be inconsistent, resulting in concentrated traffic congestion in a certain section, causing the waiting time and delay of the vehicles to be too large, and the traffic volume of the other sections. Too small is a waste of resources, and a reasonable plane intersection is set to adjust the traffic flow on the road section so that the traffic flow in the road network will not have a fault.

3. Determination of the length of the functional zone and the reasonable spacing of the intersection
Reasonable spacing not only satisfies the requirements of vehicle changing lanes, deceleration, acceleration and braking [4], but also improves the traffic capacity of road sections and increases the safety factor and traffic efficiency of road sections.

\[ D = D_{\text{down}} + L + D_{\text{up}} \]

In the formula: \( D_{\text{down}} \) is length of downstream functional area of intersection 1; \( L \) is interleaving length; \( D_{\text{up}} \) is length of upstream functional area of intersection 2.

3.1. Length of the upstream functional section of the intersection
The length of the upstream functional zone of the intersection includes the vehicle sensing-reaction travel distance \( d_3 \), the deceleration travel distance \( d_2 \), and the vehicle queue length \( d_1 \), \( D_{\text{up}} = d_1 + d_2 + d_3 \).

\[ d_3 = \frac{Vt}{3.6} \]

In the formula: \( V \) is vehicle speed(km/h); \( t \) is sense-reaction time (s), \( t \) is 2.5s [5].

\( d_2 \) is determined by the distance moved by the lateral offset and the distance moved by the lateral offset. The speed of lateral movement is 0.9 m/s; related research shows that when the vehicle moves laterally, when the deceleration rate of the vehicle is greater than or equal to 1.1 m/s², the speed difference between the vehicle and the straight lane will be greater than 16 km/h. The coordination of speed is very important for driving safety, considering the safe deceleration rate of 1.1 m/s². When the
vehicle does not require lateral movement, 85% of the vehicles will travel at a deceleration rate of 1.8 m/s² and 50% will use a deceleration rate of 2.7 m/s² or higher [6].

d₁ is the length of the vehicle queue. In the secondary road stop control management intersection, when the main road and the secondary road collide at the intersection, the main road vehicle can pass preferentially, and the main road vehicle does not need to wait in line, and the vehicle queue length is taken to be zero [7].

### Table 1. Upstream functional area range table without signalized intersection

| V(km/h) | 50 | 60 | 70 | 80 | 90 | 100 |
|---------|----|----|----|----|----|-----|
| d₁      | 0  | 0  | 0  | 0  | 0  | 0   |
| d₂      | 73 | 101| 133| 170| 211| 256 |
| d₃      | 35 | 42 | 49 | 56 | 63 | 69  |
| dᵤₚ     | 108| 143| 182| 226| 274| 325 |

3.2. Length of the downstream functional section of the intersection

The range of the downstream functional zone is mainly determined by three indicators: parking line of sight, right turn conflict, and left turn vehicle.

Parking line of sight. In order to ensure safe driving, if the vehicle does not enter the downstream of the functional area, if there is a conflict in the lateral vehicle interference, etc., it can have enough time to decelerate and stop to avoid accidents. Therefore, the parking line of sight must be met.

Right turn conflict. Vehicles that go straight at the intersection of the intersection need not only accelerate in the downstream functional area, but also pay attention to the import or traversal of the vehicle and the access lane vehicle that are right-turned at the intersection.

Left turn vehicle. For left-turning vehicles, it takes at least 2.0 s for the driver to leave or flow into the straight traffic, which is about 13 to 18 m.

In summary, the length of the downstream functional area is: 

\[ D_{down} = \frac{v}{3.6} + \frac{v^2}{254\phi} \]

In the formula:

- v is vehicle running speed(km/h), when the design speed is 100–80km/h, 85% of the design speed is adopted; when the design speed is 60km/h, 90% of the design speed is adopted.
- t is sense-reaction time (s), t is 2.5s.
- \( \phi \) is the coefficient of friction, generally taking the value of \( \phi \) in the wet state of the road surface.

### Table 2. Downstream functional area length range table

| V(km/h) | 50 | 60 | 70 | 80 | 90 | 100 |
|---------|----|----|----|----|----|-----|
| Dₜₜₕ   | 45 | 70 | 95 | 110| 135| 160 |

3.3. Smooth running length

The length of the smooth running section is based on the minimum length of the straight line between the curves specified in [1], the general value is 6V, the critical value is 2V, and the length of the smooth running section must meet the requirements of vehicle interweaving. Interlace length = road speed × single lane number × 2.

### Table 3. Interlace length and smooth running length (accurate to 5m)

| V(km/h) | 2 lanes | 3 lanes | 4 lanes | General value 6V |
|---------|---------|---------|---------|-----------------|
| 50      | 55      | 85      | 115     | 300             |
| 60      | 70      | 100     | 135     | 360             |
| 70      | 60      | 115     | 155     | 420             |
| 80      | 90      | 135     | 180     | 480             |
| 90      | 100     | 150     | 200     | 540             |
| 100     | 110     | 165     | 225     | 600             |
3.4. Reasonable spacing of intersections
Calculate the model according to the safety spacing of adjacent intersections of highways, and finally obtain the recommended value of reasonable spacing.

Table 4. Recommended distance of reasonable spacing of adjacent intersections of highways

| V(km/h) | 50  | 60  | 70  | 80  | 90  | 100 |
|---------|-----|-----|-----|-----|-----|-----|
| D       | 500 | 600 | 700 | 900 | 1000| 1100|

4. Conclusion
This paper analyses the traffic flow characteristics of road sections between highway intersections, divides the intersections of plane intersections, analyses and calculates the lengths of upstream functional zones, downstream functional zones and smooth running sections, and gives reasonable spacing suggestions at different design speeds. Reasonable spacing can not only improve the safety of vehicle driving, but also improve the operational efficiency of road traffic. But the division between adjacent intersections is only theoretical analysis, lack of actual data and simulation software verification.

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