Journal of Civil Engineering and Urban Planning (2024)
Clausius Scientific Press, Canada
DOI: 10.23977/jceup.2024.060109
ISSN 2616-3969 Vol. 6 Num. 1

Research on optimization design of highway route alignment based on vehicle operating speeds

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Keywords: Road engineering; route design; operating speed; optimization

Abstract: Vehicle running speed is the core evaluation index in highway alignment design, which is directly related to road safety and comfort. This study explores a variety of factors affecting vehicle speed, including driver behavior, vehicle type, and route characteristics, and introduces in detail the criteria and methods for evaluating vehicle speed coordination. Through the analysis of practical engineering cases, this paper not only expounds the importance of highway route alignment optimization design, but also provides specific design suggestions and optimization measures, which provides practical reference for similar projects. This study emphasizes that by comprehensively considering the coordination of vehicle running speed, the safety and driving comfort of highway design can be effectively improved.

1. Introduction

The speed of vehicle operation can reflect the quality of highway route design. Any sudden change of highway line shape will bring influence to the driver's operation and easily cause traffic accidents. A number of research results at home and abroad show that the coordination of vehicle running speed has a close relationship with the incidence of traffic accidents. Therefore, in the design of highway routes, by evaluating the coordination of vehicle running speed, we can find out the discontinuous sections of the linear design, so as to improve the safety and comfort of road traveling.

2. Influencing factors of vehicle operating speed

There are many factors, both subjective and objective, that affect the size of a vehicle's operating speed. The subjective factor is mainly the driver's behavior, and the objective factor is the type of vehicle and highway characteristics.

(1) Driver's behavior plays a dominant role in vehicle operating speed. Vehicle running speed largely reflects the driver's behavior and driving habits. Usually, in the straight section and the flat curve section, the driver will choose different traveling speeds according to their own driving experience. In the straight section, the driver will choose a relatively safe and stable driving speed to move forward at a constant speed; in the flat curve section, the driver will usually "decelerate - constant speed - accelerate" way of driving[1].

(2) According to the provisions of the Specification for Safety Evaluation of Highway Projects

(JTG B05-2015) (hereinafter referred to as the "Safety Specification"), the representative car models used for the prediction of highway operating speeds at the preliminary design stage and the construction drawings design stage are: small cars and large cars. Small vehicles have the characteristics of small load and good maneuverability, and in the "Highway Route Design Specification" (JTG D20-2017), the standard model for traffic volume conversion is a minibus. And large vehicles, especially heavy vehicles, have large loads, slow travel speeds, poor maneuverability, and are prone to traffic accidents[2]. Therefore, when designing highways, the vehicle size and driving characteristics of large vehicles need to be considered according to the composition of local traffic volume, so as to ensure driving safety.

(3) The highway characteristics that have an impact on vehicle operating speed mainly include straight lines, flat curves, longitudinal slopes and longitudinal and flat combinations of linear elements. Research shows that the length of the straight line section has a greater impact on the vehicle running speed, the straight line section is too short, the vehicle running speed has no significant change, when the straight line section is longer, the vehicle running speed will also be accelerated. The radius of flat curve section is the key index that affects the running speed of the vehicle, the smaller the radius of flat curve, the lower the running speed of the vehicle. When the vehicle is traveling on the slope, the larger the longitudinal slope is, the faster the acceleration and deceleration process is, and vice versa, the slower it is. An unsuitable combination of flat and longitudinal gradients can lead to poor sight distance and have an impact on vehicle operating speed. In addition, roadside interference can also have an adverse effect on vehicle operating speed.

Therefore, when designing the alignment of highway routes, the impact of the above factors on the operating speed of vehicles must be considered to ensure their driving safety.

3. Coordination of vehicle operating speeds Evaluation

3.1 Evaluation Criteria for Vehicle Operation Speed Coordination

According to research, there is a close relationship between the coordination of vehicle operating speeds and the incidence of traffic accidents. Therefore, in the design of highway, it is necessary to evaluate the coordination of vehicle speed, which is an important part of highway safety design. In our country, according to the requirements of "safety specification", when the design speed is less than or equal to 80Km/h, it is necessary to carry out the evaluation of the coordination of vehicle speed. The evaluation criterion is the difference between the operating speed V_{85} and the design speed $V \left|\Delta V_{85}\right|$ on the neighboring and the same road section. When $\left|\Delta V_{85}\right|$ >20Km/h, the various linear indexes determined according to the design speed are difficult to meet the needs of the vehicle operating speed, and traffic accidents are likely to occur[3]. Table 1 shows the evaluation criteria for the coordination of the operating speed of neighboring road sections.

The operating speed gradient is a complementary indicator for evaluating the coordination of vehicle operating speeds in neighboring road sections. It can reflect the changes and sensitivity of running speed within a certain route length (100m in the "Safety Code"). This indicator is closer to the actual situation and helps to find the road sections with traffic safety hazards. The absolute value of the running speed gradient $\left|\Delta I_v\right|$ is calculated as follows[4]:

$$\left|\Delta I_v\right| = \frac{\left|\Delta V_{85}\right|}{L} \times 100$$

Where: $\left|\Delta I_v\right|$——Absolute value of running speed gradient (Km/h-m);

$|\Delta V_{85}|$—— Absolute value of the difference between the starting and ending operating speeds of the analyzed unit (Km/h);

L ——length of the analyzed unit section (m).

Table 1: Evaluation Criteria for the Coordination of Operating Speeds of Adjacent Road Sections

Class of road	**Evaluation criteria**	**Coordination evaluation**	**Countermeasures and recommendations**
Highways, primary roads	$|\Delta V_{85}|$<10Km/h and $|\Delta I_v|$ ≤10 (Km/h-m)	(of an unmarried couple) be close	/
	10Km/h ≤$|\Delta V_{85}|$ <20Km/h and $|\Delta I_v|$ ≤10 (Km/h-m)	rather or relatively good	When the adjacent road section is a deceleration, it is advisable to optimize the level and longitudinal design of the adjacent road section, or to take safety improvement measures
	$|\Delta V_{85}|$≥20Km/h or $|\Delta I_v|$ >10 (Km/h-m)	unhealthy	When the adjacent road section is a deceleration, the level and vertical surface design of the adjacent road section should be adjusted, and when it is difficult to adjust, safety improvement measures should be taken
Secondary roads, tertiary roads	$|\Delta V_{85}|$<20Km/h and $|\Delta I_v|$ ≤15 (Km/h-m)	(of an unmarried couple) be close	/
	$|\Delta V_{85}|$≥20Km/h or $|\Delta I_v|$ >15 (Km/h-m)	unhealthy	When the adjacent road section is a deceleration, the level and longitudinal design of the adjacent road section should be adjusted, or safety improvement measures should be taken

3.2 Evaluation method of vehicle operation speed coordination

When evaluating the coordination of vehicle operation speed, it is first necessary to analyze the division of road sections according to the size of the radius of the flat curve and the longitudinal slope. Generally, it is divided into flat section, longitudinal slope section, small radius flat curve section and curved slope combination section. Then, according to the prediction model in the "safety specification", the vehicle operating speed is calculated, and the difference between the operating speed V_{85} and the design speed $V|\Delta V_{85}|$ and the operating speed gradient $|\Delta I_v|$ are obtained, and the results of the evaluation of the coordination of the vehicle operating speed are shown in Table 1. The coordination evaluation method of vehicle running speed is shown in Figure 1.

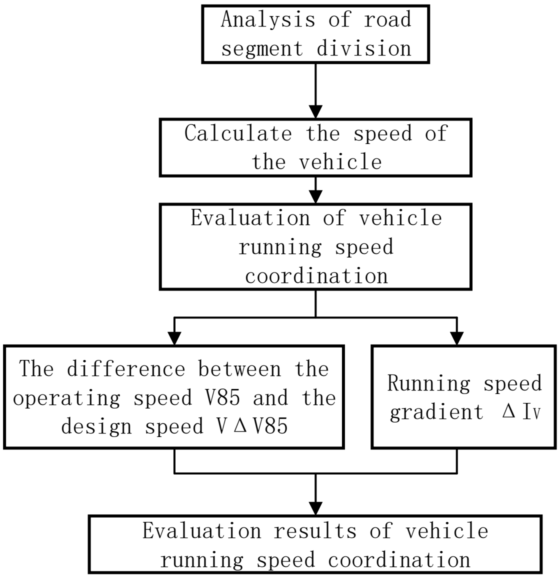

Figure 1: Coordination evaluation method of vehicle operating speeds

4. Example analysis

This paper combines G209 line Lvliang new city (Fangshan County to Zhongyang Jinluo Town) section of the highway preliminary design engineering examples of the coordination of vehicle operating speed and highway route line optimization design aspects of the problem to analyze and demonstrate.

4.1 Overview of the project

The starting point of the project is located in Fangshan County, Massachusetts Hill Township, Zhaozhuang South end point in the form of interoperable three-dimensional intersection with the National Highway 209 Provincial Highway 340 Zhongyang County Transit Highway Rerouting Project, the route length of 58.185 kilometers (including the chain of breaks: 0.185 kilometers). The whole line according to two-way four-lane first-class highway standard construction, the design speed of 80Km / h, roadbed width of 25.5m, separated from the roadbed for 12.75m; connection line according to the construction of second-class highway standards, the design speed of 60km / h, roadbed width of 12m.

4.2 Analysis of Transportation Vehicle Types

The section of national highway 209 (Lyuliang section) is closely related to the route corridor. According to the statistical analysis of the traffic composition of the national highway 209, the analysis results show that in the regional traffic composition, the proportion of trucks is large, accounting for more than 85.0 % of the total traffic. Among them, trucks are mainly large trucks, super-large trucks and container trucks, accounting for more than 65 % of the total travel.

According to the characteristics of this project, the overall design of the project emphasizes driving comfort and safety, and according to the "safety specification" for the whole line of running speed calculation and safety evaluation, to improve the safety of the highway itself.

4.3 Vehicle Operating Speed Evaluation of Highway Alignment Designs of steps

According to the plane, longitudinal section and cross-section design results of the preliminary design, the running speeds of minibuses and large trucks in different traffic directions (upward and downward) within the divided linear unit are evaluated in a coordinated manner. When the evaluation result is "good", it means that traffic safety, route design scheme is feasible; when the evaluation result is "better" or "bad", it is necessary to optimize the route line design or adjust[5]. Vehicle speed evaluation highway alignment design steps are shown in Figure 2.

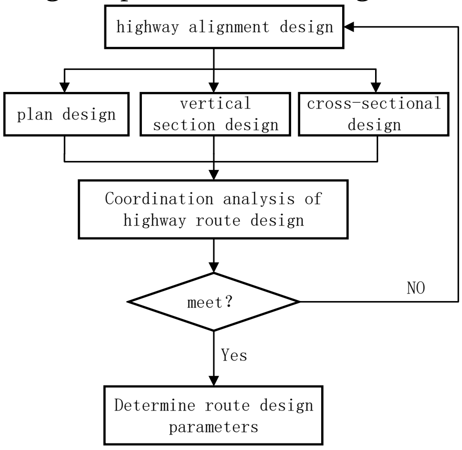

Figure 2: Vehicle operating speed evaluation of highway alignment design steps

4.4 Vehicle Operation Speed Coordination Optimization Measures

According to the prediction model in the ' safety specification ', this paper optimizes the alignment of the road sections with ' good ' or ' bad ' vehicle speed results, or takes safety improvement measures.

4.4.1 Graphic design optimization

(1) Flat curve radius. In the case of transverse force coefficient and road arch cross slope unchanged, the radius of the level curve can be back calculated by the vehicle running speed, and it will be compared and analyzed with the radius of the level curve corresponding to the reduction of the vehicle running speed, so as to choose the best from the economic point of view. When the adjustment of level curve radius and road arch transverse gradient is restricted, measures such as speed limit can be taken, so as to ensure that the difference between running speed and design speed is less than 10Km/h.

(2) Easing curve. By back-calculating the radius of flat curve and super-high gradient through vehicle running speed, the length of the adjusted easing curve should meet the minimum length requirement of super-high gradient rate. In addition, it is necessary to consider the change in the length of the easing curve due to the change in the rate of change of lateral acceleration.

(3) Minimum straight line length. The minimum straight line length calculated according to the operating speed of the vehicle should meet the following requirements: the minimum length of the straight line between the same curve (in m) should be greater than or equal to the operating speed of V85 (in Km) 6 times; the minimum length of the straight line between the curve in the opposite direction (in m) should be greater than or equal to the operating speed of V85 (in Km) 2 times.

4.4.2 Longitudinal section design optimization

Vehicle operating speed does not meet the requirements of the longitudinal slope section, the most direct and effective measure is to adjust the longitudinal slope and slope length. The greater the gradient of the longitudinal slope, the greater the operating speed of the vehicle on a downhill slope. The longer the length of the longitudinal slope, the greater the change in vehicle operating speed. In the uphill and downhill sections, by adjusting the slope gradient and slope length, thus ensuring that the vehicle running speed coordination to meet the requirements.

4.4.3 Cross-section design optimization

The design speed of the project is 80Km/h, corresponding to the permissible minimum speed of 50Km/h. When the operating speed of heavy vehicles is lower than 50Km/h, a climbing lane should be set up on the right side of the uphill direction of the steeply sloping road section, so as to ensure the safety of traffic and improve the capacity of the road section.

4.4.4 Optimization of travel sight distance design

In this paper, the design speed and vehicle running speed are used to calculate the driving sight distance, and the larger driving sight distance is used as the design parking sight distance. In road sections dominated by heavy vehicles such as large trucks, the driving sight distance requirement calculated using the vehicle operating speed of large trucks should also be met[6].

4.5 Analysis of the optimization effect of highway route alignment design

Highway route design after optimization, through the vehicle operating speed simulation test for coordination evaluation, the expected operating speed of minibuses can be maintained above 90Km/h, the expected operating speed of large trucks most of the road sections can basically be maintained above 50Km/h, the local operating speed of the lower road sections set up a climbing lane. The running speed difference between adjacent sections is basically controlled within 20Km/h, which meets the requirement of running speed coordination. In summary, this project has good linear continuity, balanced indexes, and meets the requirement of running speed coordination.

5. Conclusion

In summary, the design of highway route alignment is a continuous optimization process. Using the difference between the running speed V_{85} and the design speed $V\left|\Delta V_{85}\right|$ and the running speed gradient$\left|\Delta I_v\right|$, we can evaluate the coordination of the vehicle running speed, and then find out the unsafe sections in the design and optimize the design, so as to ensure the safety of driving and provide a safe and comfortable driving environment for the drivers.

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