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Analysis on Safety Influencing Factors on Highway Interchange Design

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Abstract: This paper briefly introduces the safety performance of the highway interchange design. The factors that influence the safety of the highway interchange design, was discussed in the paper based on the parts, which are the safety of the interchange location, the safety of interchange form, and the safety design of the main line in interchange.

Keywords: Highway; Design of interchange; Security; Safety performance

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1. Introduction

Interchange is not only an important hub of traffic transformation, but also an intersection for centralized and decentralized vehicles. The safety performance of the interchange design, is mainly about the safety of the people, roads, and vehicles. The design of the interchange has a great impact on improving the highway capacity, promoting the overall development of the local economy, comprehensively improving the overall level of highways, and ensuring traffic operation efficiency. Scientific design or symbols and perfect notice signs, and remarks can make people to have a better sense of direction while travelling [1]. In order to follow the driver's behavior, and to meet the needs for the vehicles to travel, scientific linear design must be carried out. Sufficient sight design and symbols are required to meet the requirements of driver response time with the actual normal operation time [2]. Therefore, the safety performance design of an interchange, can reduce traffic accidents to a certain extent, subsequently, improve the traffic capacity of road networks, further reflecting the function of harmonious operation. The traffic operation of the interchange area, is more complicated compared to the ordinary section, and there is a frequent split-merge behaviors, which can contribute to traffic accidents. In order, to renovate and expand the interchange, some technical indicators are followed according to the minimum recommended value in the code, and even the limit value is followed. The combination of these low limit indicators, may aggravate the complexity of the operation conditions in the interchange area. Therefore, it is important to conduct a proper investigation and evaluation of the road status for the selection of the construction scheme to be used for the interchange.

2. Safety impact of interchange location

In the terms of safety of the interchange location, the minimum distance between adjacent interchange, interchange, and other structures must be followed. For the general urban highways, the design of the interchange spacing is smaller, compared to the expressway, and its setting parameters can be followed as

shown in **Table 1**. According to the relevant studies in China and abroad, the interchange spacing plays an important role, ensuring the uniformity flow of the road traffic because, interchange can affect the coordination of the traffic organization in the whole highway area [3].

Table 1. Spacing of urban highway interchange

Spacing type		Spacing setting parameters
Standard spacing		Large cities and industrial parks are 5 ~ 10km, and general areas are 15 ~ 25km
Maximum spacing		30km
Minimum spacing		4km
Spacing requirements with other facilities	Service area and parking lot	It is usually 5km and the minimum is 3km
	Bus station	It is usually 4km and the minimum is 1.5km

The distance between the adjacent interchanges should be properly measured and reasonably controlled, because if the adjacent is too large, it makes no contribution to the traffic diversion, meanwhile if it is too short, it will undoubtedly aggravate the turbulence of the traffic flow in the adjacent intersections, subsequently increase the incidence of accidents. The distance between the adjacent expressways, and relevant service facilities are required to follow the same principle. Compared to the interchange, the traffic flow entering the service facilities is generally small, and the interference with the straight-line traffic is very small. The distance between the interchange entrance and the tunnel entrance is mainly controlled by the sight requirement of the approaching vehicles recognizing the two adjacent structures. When, the interchange entrance is in the front of the tunnel entrance, there is no problem with the line of the sight recognition and it is safe to drive. In contrast, when the interchange exit is behind the tunnel exit, the tunnel is short, making the driving is relatively safe, however, the visibility is low and unobstructed [4]. Therefore, in order to ensure the traffic safety of the vehicles, the interconnection exit should be located behind the tunnel exit, and the tunnel has to be long, with the spacing must meet the requirements of the relevant regulations, with a complete exit guidance sign section should be placed at the tunnel exit. In the face of special terrain, if the installation position of the interchange cannot be adjusted, or the spacing cannot be adjusted to meet the requirements of the relevant regulations, the particular interchange exit should have guidance signs placed in the tunnel.

3. Safety impact of exchange form

As a three-dimensional transportation mode, the choice of the interchange design is often influenced by many factors, such as node terrain, traffic volume, traffic configuration and also the requirements setting for the toll station [2]. In designing the interchange design, the choice of interchange type is the key link, where a specific interchange type can directly determine the smoothness of road network and the traffic transition between the roads and the safety of nodes.

The specific form of interchange design process, is largely determined according by the layout of the ramp, which is closely related to the terrain, and the surrounding environment of the site. The right turn ramp must be directly connected, meanwhile the left turn ramp can be either semi-directed or circular, depending on the amount of rotation, and usually is not directly connected. According to the various vehicle trajectories, semi direct connection can be further divided into internal rotation, external rotation, and circuitous semi-direct connection. Different forms of the light combination are used, to forms different

communication mode, therefore, there are around hundreds of interchange forms in a three-way interchange, meanwhile, around tens thousands of interchange forms in the four-way interchange [5]. However, in the actual engineering design, most of the interchanges are formed by a linear combination with no practical values. The interchange layout that is followed in a specific project, should be compact, and also the bridges and other structures should be minimized, in order to reduce the scale and the cost of the project. There are not many common forms of interaction in the element and the engineering design [6]. The accident rate at the exit interchange is usually higher, compare to the other ramp sections, because the speed of the vehicles entering the ramp is usually higher, than the main line. The influence of the interchange's form entrance, and exit on the safety is mainly reflected, by the structure of the interchange's entrance and exit, and the traffic capacity that is can provide. The small signs in the horizontal and vertical directions of the main road and ramp at the entrance and exit are easy be missed by driver's who is lack of vision. Therefore, it is necessary to timely identify the vehicle flow at the exit ahead, or before entering the main road. In an emergency situation, if there is no sufficient time to completely reduce the vehicle speed, or deceleration, the risk of having traffic accidents is higher. Additionally, in the case of continuous entrance and exit of the interchange, the vehicles at the entrance and exit should be prevented from interfering with each other, to ensure the safety of the vehicles.

4. Safety design of interchange main line

Generally, the gradient of the interchange should not be exceeding the maximum value specified in the gradient range. If the gradient of the main line is smaller, the longitudinal gradient of the ramp, and the corresponding interconnection scale should be smaller as well [7]. Additionally, in the case of hub interchange, due to the limitation in the location and terrain, the intersection between the main line, and the intersection is relatively uniform, and the gradient of the intersection may exceed the maximum value required by the specification. In a usual condition, the length and lanes of the acceleration and deceleration is corrected, while, the warning signs for deceleration and descent is set to compensate the slope exceeding the main line of sight distance.

Although visibility is very important, the calculation of the driving distance is affected not only by the shape of the straight line, but also by the characteristics of ground, bridge, culvert and terrain, and there are many restrictive factors, which can be easily omitted. There are many factors, that can affect the visibility of the main line, such as vertical slope, bridge, and turning radius [8]. The impact of the vertical slope is quite serious on the vertical section, where the driver's sight can be easily blocked on the vertical curve, which is connecting the uphill and downhill. The smaller the vertical curve radius, will have a more serious effect on the sight, therefore, if the line of sight did not meet the specified value will result in insufficient line of sight for a section. Additionally, if the radius of the convex vertical curve of the road is too small, it will further affect, and narrows the driver's field of vision, therefore, an exit position cannot be designed after the small-radius convex curve. The overhead bridge is hollowed with variable slope sections, and has a greater impact on the vertical sections of the uphill and downhill. When driving during the night, when the vertical curve radius is small, the range that the lamp which can illuminate is blocked, resulting in the blockage of the driver's line of sight, subsequently, the line of the sight distance does not meet the specified value, leading to traffic accidents [9]. Therefore, it is necessary to design a scientific vertical turning radius on the basis of ensuring driving time and safety [10]. Roadside obstacles, such as facilities, buildings, trees, slope excavation, and others, especially on the road curve, may affect the driver's line of sight, therefore, it is important to identify and remove the roadside obstacles, which can affect the driver's visibility. The deceleration lane length is, generally, considered to be in the minimum value, where the length could not meet the acceleration and deceleration needs of drivers on the road, not following the standard specification, where the length compensation for uphill acceleration and downhill deceleration [1]. As a part of the design,

if the length of the deceleration lane has not been calibrated by the staff, and the deceleration length specified in the specification is not adopted, can affect the vehicle operation, and cause traffic accidents due to deceleration delay. When the detour traffic flow is too large, due to the mutual restriction of the detour vehicles and the main road vehicles, the degree of freedom of vehicles in the detour area is reduced, which is easy to cause road traffic congestion, and then results in traffic congestion. Increasing the length of deceleration lane, further can reduce congestion. In a practical application, the calculation of deceleration lane must also be combined with the size of traffic flow in the section [11].

The expressway with direct deceleration lane is directly connected with the main line by a certain deflection angle, that is, the outflow angle of the deceleration lane. Too large or too small of the runoff angle setting, will bring safety risks, and resource waste to drivers and to the road design [12]. When setting the deceleration lane on the slope, the impact of the slope should be considered. In the downhill section, due to the action of gravity, deceleration amplitude decreases, and the greater the deceleration amplitude is.

The difference between the design speed of the main line, and the ramp determines the starting point, intersection, fork, and running speed of the ramp segment, thus affecting the length of the decelerated lane. In particular, the greater the speed difference between the turning point and the turning nose, the longer the length of the deceleration lane required for the vehicle to safely enter the ramp.

5. Clear distance between interchange spacing influence factor

5.1. Road network layout and the communication function

The location of the interchanges should be chosen in accordance with the applicable network planning and local roads should be serviced by short distances up and down expressways. In the hub interchange type, intersecting roads have high functional level, and unclear traffic flow, which may play an important role in the overall road structure [13]. As a traffic conversion mode, if the interval is set too large, the service level of the main road, and the whole road network will further be reduced.

5.2. Expressway service level

Due to the rapid development of China and the rapid growth of local road traffic, the service level after the reconstruction and expansion of the interchange may reach saturation in a short time, which may significantly reduce the service level of the section [14]. Therefore, if the distance between the two interchanges is too close, the highway can become congested at certain sections, increasing travel delays, and becoming a ‘bottleneck,’ affecting the service level of the entire section.

5.3. Traffic density

The higher the traffic flow density, the greater the influence of the expressway merging. A reasonable net distance disturbance will affect the intersecting roads, reasonably distribute the traffic flow, and balance the traffic density of the whole road network, and also prevent a sudden change in the traffic density. A set transfer is closely related to traffic density.

5.4. Characteristics of traffic flow in expressway interconnection area

Drivers, who are preparing to enter the main road in the interchange area adjust their driving behavior, according to the traffic situation on the main road, and should enter into the main road as soon as possible [15]. In the interchange transition area, detour vehicles, must leave the main line, and be separated from public transportation, in order to leave the interchange and the main line safely. The frequent lane change behavior of the vehicles at the intersection, can affect the vehicles which are driving straight on the main road. Therefore, there must be enough clearance space between adjacent interchanges, to meet the lane change requirements for entering and leaving the expressway.

5.5. Requirements for comfortable driving

The net distance between two overpasses greatly affects the comfort and safety of driving. In the process of exit identification, drivers must complete a series of exit actions by adjusting their driving behaviors, according to the traffic conditions of adjacent lanes [16]. If the distance is too close, the driver has to receive a large amount of information in a short period of time, increasing the traffic load, resulting in operational errors, leading to traffic accidents.

5.6. Requirements for installation of traffic signs

It is necessary to place appropriate traffic signs on a sufficiently long section to remind the driver to change lanes as soon as possible before the driver leaves the highway. Setting up traffic signs is very important for intercity drivers, who are not familiar with highway conditions or cannot recognize the location of the front exit due to the bad weather. Between two adjacent ICs, the driver enters the main line of the previous IC through the confluence area, change lanes, and then runs smoothly. After seeing the exit traffic sign and confirming that it is the target exit, the driver changes lanes again to overtake [17]. After passing through the bypass area, the car gets into the latter overpass, therefore, the net distance of the freeway interchange is closely related to the setting of the traffic signs.

If the minimum clearance of tunnel exits and interchange exit does not meet the requirements, the interchange must be moved to a position that meets the clearance, if the conditions permit. It should not affect the distance and the exit identification, therefore, a separate interchange can be considered. This method can completely solve the problem when the tunnel exit, and communication exit is too close, however, for the reconstruction and expansion project, relocation, and reconstruction, meaning the need for new land, leading to increase in the project cost.

6. Conclusion

To sum up, the new concept of interchange design must be applied to achieve better results. The construction unit also needs to be updated based on the new design concept, strengthen the exchange, and learning with international advanced technology, and constantly apply advanced technology to improve the highway design. The application of advanced design concepts in the structural design of interchange highway, can improve the rationality of traffic operation, ensure driver safety, and subsequently, meets the needs of local traffic operation. According to the requirements of reliability and feasibility, we could make the road more scientific and reasonable to meet the needs of local traffic operations.

Disclosure statement

The authors declare no conflict of interest.

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