Discussion of active safety countermeasures of motorway work zone

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Abstract. A series of comparison analyses of work zone configurations, traffic organizations and work management among China and oversea countries are carried out. Taking into consideration of human, vehicles, roads, environment as well as management factors, the causes of traffic accidents in work zone areas are deeply discussed. Based on road safety in work zone areas, a series of active traffic safety improvement countermeasures for both workers and drivers in work zone areas have been introduced from the respects from traditional safety devices and traffic control measures to information and intelligent measures, which will provide inspires for the improvement of work safety and operation safety in work zone areas.

1. Introduction
The increasing time of highway in operation in China leads to more road maintenance, and the demands for reconstruction and expansion of some existing two-way four-lane motorways are rising higher day by day. Under the circumstances, the vehicles passing through the work zone will inevitably affect the workers and the construction machinery, resulting in serious safety risks in the road sections near the work zone areas. One of the typical situations is that the vehicles intrude into the work zone areas, which make the workers injured and construction facilities damaged after crashes. At present, the settings and control management of road safety devices in work zones in China are mainly complying with the requirements of the prevailing Safety Work Rules for Highway Maintenance (JTG H30-2015) [1]. However, the existing measures only warn the through traffic, but not workers in work zones. Serious injuries and damages will happen to the construction workers and facilities once there are errant vehicles intruding into the work zone areas, especially the large trucks intrusion. In the view of these cases, in-depth study on the traffic accident causes of work zones and the analyses of safety countermeasures are critical to the road safety improvement in work zones.

2. Development of work zones
2.1. Traffic safety in work zone areas
The space distribution analysis of traffic accidents is carried out combined with the configuration of the work zone, traffic accidents are more likely to occur in the work area, the upstream transition area, and the buffer area, accounting for 35%, 23%, and 20% of the total, respectively. Thus, the upstream section is an traffic accident aggregating area, which is normally caused by changes in road conditions and complex traffic flow conditions.
2.2. Development of work zone facilities
At present, the configuration of work zones in European countries and the United States are basically consistent, covering an advance warning zone, two transition zones, an work area, a termination zone [2]. The configuration of the work zone in China is similar to that in the United States, covering five zones, namely, an advance warning area, transition areas, a longitudinal buffer area, an activity area, and a termination area [3]. Additionally, the transition areas in China consists of the longitudinal transition area and the transverse buffer area, and the longitudinal transition area is further divided into two areas by upstream and downstream. There is basically no difference in the definitions of the areas with the same name, but the transition area is further divided into the narrowing area and the stable area. It is worth noting that in Europe, a departure zone is added to the point where the end point of the termination area is restored to the original cross section, so as to set a sign indicating the end of the traffic control, thus improving the driving safety in the work zone.

2.3. Traffic organization in work zones
Expansion projects generally require traffic control, therefore, the construction management scheme must be formulated by taking into consideration the traffic organization scheme. Previous construction management schemes of expansion projects can be divided into six types: fully-closed construction, half-closed construction, full-formation vehicle type dependent diversion construction, half-formation vehicle type dependent diversion construction, traffic open construction, and combined construction [4]. In addition to the fully-closed construction and half-closed construction, other types of schemes all exert the impacts on traffic operations and road traffic safety that great attentions are needed.

The research of traffic organizations mainly focuses on the traffic diversion and the control of driving behaviors, which should be integrally applied. The traffic diversion includes diversion for road network, diversion for side roads, and diversion for construction roads, while the control of driving behaviors is divided into speed limit dependent pass, time limit dependent pass, and lane division. Based on the main construction organizations with considerable safety impacts, the control of driving behaviors is the prevailing traffic organization measure, in the way of setting temporary devices such as speed limit signs and pavement markings to make driver informed and passing at comfortable speeds, or restricting the passage of vehicles through a limited time duration, or limiting vehicle passage at certain time periods, or adjusting the configuration of carriageways and carrying out traffic diversion by carriageway reconfiguration.

3. Analyses of traffic safety causes in work zones
3.1. Human factors
From the current analysis of the causes of traffic accidents, the human factor is related to more than 90% of traffic accidents and most traffic accidents in the work zone. Since the construction site concerns the activities of traffic and construction operation, the human mentioned here includes the vehicle driver and the construction worker. From the driver's point of view, the main factors leading to accidents are usually fatigue driving and improper operation, improper speed control while
approaching the work area, speeding, and intrusion into the work area due to late speed reduction. As for construction workers, the main causes are arbitrarily driveway invasion by construction workers or vehicles, and improper placement of the construction facilities.

3.2. Vehicle factors
Vehicles are driven by people, so the vehicle factor is often closely related to the driver's operation. However, due to the great change in the road conditions in the work zone, such as the cross section closed for construction, lane change, narrow lanes, etc., the road section in which high percentage of large trucks road traffic tends to be more disturbed than the general road section. Particularly, once the large truck fails to change lane timely, it is easily resulting in congestion in the upstream transition area. The vehicles in the upstream traffic are difficult to make timely reaction due to sight blockage by the large trucks which leads to rear-end traffic accidents, and they even intrude into the work area causing serious injured traffic accident [5].

3.3. Road factors
The road factor mainly includes the road geometric alignment along the work zone, the configuration change of the cross-section, the rationality of the settings of traffic safety devices such as the traffic signs and road markings in the work zone and the roadside barriers, etc., all of which are the influencing factors with their own characteristics of accidents.

3.4. Surrounding and environment factors
Severe meteorological conditions such as rain, snow and fog are often the main environmental causes of road traffic accidents. Due to the complicated road and traffic flow conditions of the work zone, the above factors will further aggravate the safety. For example, in rainy and foggy days, the driver's sight is affected due to low visibility, so the warning signs arranged in a conventional manner might fail to meet the requirements. At the same time, coupled with the lower friction coefficient of the road pavement in rainy and snowy days, the vehicle is more likely to slip, which might lead to traffic accidents. In addition, uncovered construction machinery and personnel inside the work area tend to distract drivers, which might also cause traffic accidents.

3.5. Management factors
In addition to the four main factors mentioned above, the management of the work zone is also very important. For example, if the workers operate and stack materials according to regulations, set lighting facilities at night and warning facilities in the upstream transition area, control and manage the construction based on regulations under adverse weather conditions, wear properly, and conducts safety inspections, the safety of the work zone can be improved.

4. Active countermeasures for work zone safety
Active countermeasures are to enhance management, enhance safety education, simultaneous warn drivers and the construction workers, such as deploying detection and pre-warning systems to better prevent accidents. Active safety is developed based on passive safety. As a preferential safety measure, it can avoid traffic accidents by eliminating the root cause.

4.1. Education and propaganda for raising safety awareness of workers and drivers
Safety education for construction workers and drivers, including special safety training activities, safety manuals and guides handed out in service areas or construction units, and promoting traffic safety information through media such as mobile APP or radio and television, can improve the driver's awareness of the driving safety and traffic regulations, improve the safety awareness of construction workers, and raise their attention in this regard, thus avoiding or reducing the impact of construction operations on road traffic.
4.2. Develop and implementing efficient work management and traffic organization schemes
Based on the analysis of the traffic flow in the work zone, combining the configuration and the construction schemes, a rational construction and traffic organization scheme are proposed from the two aspects of traffic diversion and traffic management, so as to avoid blindly following the requirements, thus delivering a targeted and effective organization schemes suitable in local areas. Improve the traffic safety supporting facilities by means of setting warning signs, speed limit signs, work zone length warning signs, road markings, and lighting facilities can reduce traffic accidents, especially reduce the possibilities of KSI traffic accidents.

4.3. On-site detection & active warning systems
The present active safety means of intelligent traffic information in the conventional construction operation area mainly involves the on-site event of the operation section and vehicle detection and the active pre-warning device.

1) Vehicle and event detection system: At present, most vehicle detection technologies are mainly based on the detection of the traffic flow parameters such as vehicle speed and vehicle type using pneumatic tube, geomagnetic induction, radar microwave and video device. Event detection is mainly about immediately knowing the occurrence of accidents and tracking the vehicle route, the direction angle, and the speed through video, infrared, laser, the pressure sensor, among other triggers.

2) Active pre-warning device: This device is mainly about analyzing, judging, transmitting information, and proposing control schemes for data using local or remote monitoring system based on vehicles and event detection. At present, similar collision warning systems have been developed at home and abroad. For example, the United States has developed the “smart bucket”, an adaptive queuing warning system, which can detect the speed of vehicles in the work zone using passive infrared sensors, judge the state of traffic flow using algorithm, and use corresponding signals to notify the queuing situation, so as to adjust the vehicle operation in real time [6]. The test results show that drivers believe that the adaptive system is more helpful compared to the static signal control as it can significantly change their driving behaviors so as to improve traffic safety. In China, further explorations have been made in the development of active pre-warning equipments in the work zone. For example, Chang'an University has proposed a wireless sensing alarm system for the work zone and a pre-warning device for the break-down section [7]. The Research Institute of Highway the Ministry of Transport has developed a traffic safety integrated control system based on wide-area network communication technology, on-site short-range microwave communication technology, vehicle intrusion detection and sensing technology, synchronous flicker technology, and infrared laser speed measurement technology from the perspective of ensuring the safety of both drivers and construction workers. This system integrates the three functions of intrusion detection, multi-dimensional alarm and remote monitoring in the construction stage of the highway, as shown in Figure 2.

Figure2. Cooperative control systems for work zone safety.

The focus is to realize the vehicle speed control in the advance warning area, the synchronized warning and vehicle intrusion detection in the upstream transition area and the buffer area, and the multi-functional alarm in the work area. In the meantime, synchronized warning in the work area and the construction management center and the remote video monitoring should also be realized, the layout of the system is shown in Figure 3. At the same time, an information technology based terminal
for remote intelligent monitoring and management of work zone is also developed, which can monitor online, activate alarm messages, automatically record intrusion footages, view, capture, and record real-time monitoring, thus promoting intelligent management.

5. Conclusions
Through the world, work organizations and traffic organizations are generally consistent. As the rise of highlight of importance of safety for workers and drivers in work zone areas by highway administration authorities and traffic management authorities, the effects on work zone safety are gradually dependent on devices configuration and control measures as well as driving behaviors and safety awareness of workers. Although the mileage of highway has stepped into one of the major country in the world, road traffic safety, especially work zone safety, management capacity, driving behaviors and work management in work zone areas are still insufficient of uniformity and standardization, which are not satisfied with the needs of traffic development; therefore, improvements of safety for construction and operation activities are also the basic measures for developments of road traffic in China.

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