A case study of unavoidable accidents of autonomous vehicles

Zhiwei Sun, Wentao Chen, Qing Zhou, Pengfei Ying

I. INTRODUCTION

In the 1990s, Sweden proposed the Vision Zero, a strategy to eliminate traffic fatalities and severe injuries, as a goal for road safety [1]. Given that human errors cause more than 90% of road traffic accidents [2], autonomous driving technology, which eliminates human operation, is considered a promising approach to improving traffic safety [3-4]. While the development of autonomous driving technology is expected to reduce collision accidents in the future, collisions may still occur due to constraints on perceptual hardware and decision algorithms.

This study was aimed to demonstrate that unavoidable accidents can still occur despite autonomous vehicles will have advanced capabilities for perceiving and responding to risks. To achieve this objective, we investigated real-world vehicle collision accidents from the constraints imposed by vehicle dynamics and traffic environments and inferred scenarios and characteristics of future vehicles' accidents based on existing accidents.

II. METHODS

To identify future unavoidable accident scenarios, this study used existing accidents for analysis. We adopted a prospective method to evaluate whether accidents are avoidable or unavoidable under highly autonomous driving conditions. In analysing an accident, we identified a target vehicle involved in the accident and assumed it to be a near-perfect autonomous vehicle (360° perception and 0.3 s delay from perceiving to acting). Given the extreme conditions, we assumed that the perception and decision-making of autonomous vehicles are ideal or near-perfect. The target vehicle is capable of making optimal decisions in an extremely short period of time. Other participants in the accident either caused the accident (hazard) or served as interfering vehicles. Additionally, we ignored the causes of the hazard. Such an extreme situation allowed us to evaluate whether the accident is unavoidable from the point of view of vehicle dynamics and traffic environment constraints.

The method consists of the following steps: choosing appropriate accident data; reconstructing the accidents with video analyses and PC-Crash simulations; judging whether the accident is unavoidable under assumed conditions of autonomous driving technology; and summarising characteristics of unavoidable accidents.

III. INITIAL FINDINGS

After analysing 112 accidents selected from the China In-Depth Accidents Study (CIDAS) and the internet, several accidents were judged as unavoidable accidents due to insufficient time in response based on the criteria introduced above. They are characterized as "time-limited" because the vehicle dynamics and traffic environment would not allow the collision to be avoided. Below, we will introduce two typical cases.

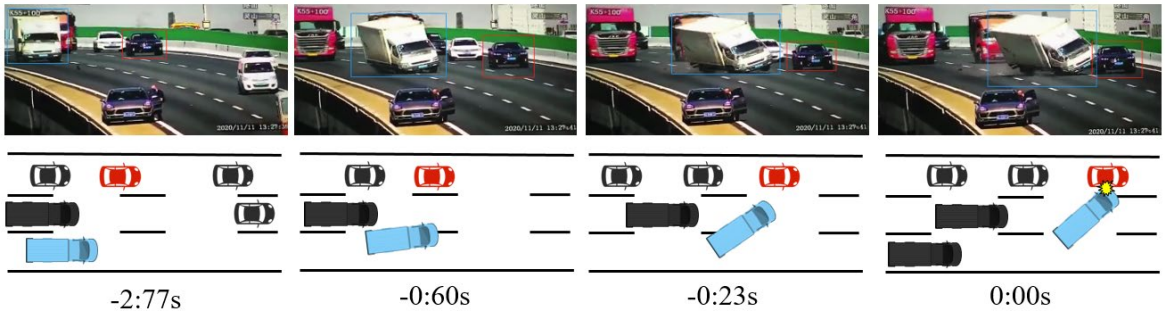

Fig. 1. Accident diagram of Case 1 (surveillance video on the road).

Case 1 involved an accident that occurred on a highway in Guangdong Province, China, in 2020. As shown in Fig. 1, a white truck (in blue frame) lost control for some reasons and collided with a normal-driving SUV in front (in red frame). From the observable kinematics change of the white truck (i.e. the signs of lost control), it took only 0.6 s to reach the collision point. The SUV was travelling at a velocity of approximately 100 km/h, estimated through video analysis. If we assume that the SUV is a highly autonomous vehicle equipped with appropriate sensors and algorithms, upon subtracting the 0.3 s delay, the remaining acting time for the SUV to avoid the

Q. Zhou (e-mail: zhouqing@tsinghua.edu.cn) is a Professor and Z. Sun, W. Chen and P. Ying are PhD students in the School of Vehicle and Mobility at Tsinghua University, China.

collision is only 0.3 s. With a friction coefficient of 0.8 on pavement, in 0.3 s, the maximum longitudinal motion would be 0.35 m, less than the distance from the collision point to the front or rear of the SUV. Apparently, the collision could not be avoided no matter if the SUV accelerated or decelerated. In fact, the SUV could not avoid the collision by steering away either because there was a guardrail on the left and a hazard on the right.

Fig. 2. Accident diagram of Case 2 (video from the target vehicle).

Figure 2 illustrates an accident that occurred on a two-lane highway caused by a blocked view. The speed of the target vehicle involved was 102 km/h. In the following description, the three vehicles involved in the accident are referred to by their coloured symbols in the accident diagram instead of by the colours of the vehicles that appeared in the video (the colours are different). Initially, three cars were travelling in the left-most lane when the blue car (the first vehicle in the platoon) suddenly hit the guardrail and lost control, becoming a hazard. The black car (the second vehicle) then applied full braking to avoid a rear-end collision with the blue car. Meanwhile, the red car (the third and target vehicle) noticed the braking of the black car (as indicated by the brake light in the second video frame) and quickly changed lane to avoid a rear-end collision with the braking vehicle. Unfortunately, the blue car spun and appeared suddenly in the right lane, leading to a collision with the red car. When the target vehicle detected the hazard and changed lane, its speed was approximately 70 km/h and it was only 29 m away from the collision point. Assuming the target vehicle is a highly autonomous vehicle with near-perfect capability, a recalculation showed that even with hard braking, the collision would still have occurred, although the collision speed would have been reduced to 14 km/h. Due to the constraints of the traffic environment, the target vehicle had no other options, such as steering away, to avoid the accident.

IV. DISCUSSION

We have demonstrated that there will still be collision accidents that cannot be avoided, even with the improvement of autonomous driving technology. For unavoidable accidents like Case 1 and Case 2, we refer to them as time-limited unavoidable accidents, meaning that vehicle does not have sufficient time to respond to suddenly emerged hazard and avoid collision. The vehicle's capability to avoid a collision is limited by its dynamics and road conditions, such as the friction coefficient between the tyre and road surface, and is also constrained by the traffic environment, such as the kinematic relation with surrounding vehicles and roadside obstacles.

The time-limited unavoidable accidents can be further divided into two sub-categories. The first is the sudden emergence of a hazard, which causes one or more traffic participants to suddenly change their motion trajectory or considerably beyond expectation, like Case 1. These kinds of hazards produce insufficient time for surrounding vehicles to respond. The second is the view occlusion, where the time from the emergence of hazard to collision is sufficient for target vehicle to act, but the hazard is initially out of perception range or the view is blocked. If the view is not blocked or the information of the hazard emergence can be relayed to the target vehicle in some way, e.g., through vehicle networks, the target vehicle might be able to act timely with correct manoeuvre to avoid the collision, like Case 2. Some of these accidents may be avoided if the entire traffic system is well connected.

This preliminary study is not broad enough to obtain sufficient characteristics of unavoidable accidents of autonomous vehicles. Future studies may include more video cases recorded by dashboard cameras and traffic surveillance cameras to identify more characteristics of unavoidable accidents.

V. ACKNOWLEDGEMENTS

This study was supported by the National Key R&D Program of China (2017YFE0118400).

VI. REFERENCES

[1] Piatkowski, D., *et al*., *Great Plains Research*, 2021.
[2] Singh, S., *NHTSA*, 2015.
[3] Bimbraw, K., *ICINCO*, 2015.
[4] Waldrop, M. M., *Nature*, 2015.