TECHBRIEF

Effects of Signing and Configuration of Partially Automated Truck Platooning On Light-Vehicle Driver Behavior

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INTRODUCTION

Partially automated truck platoons are likely to become one of the first commercially deployed forms of connected and automated vehicle technology. However, the possible effects of partially automated truck platoons on the behaviors and attitudes of light-vehicle drivers are uncertain. Early platoon deployments will probably consist of two to three trucks using cooperative adaptive cruise control (CACC) at following distances similar to distances observed on roads today. These platoons may not have significant effects on driver behavior. However, unsigned groups of trucks using CACC with shorter following distances may create unintended negative perceptions and outcomes. Light-vehicle drivers may perceive platoons with shorter following distances as displaying risky or aggressive driving. Platoons using longer following distances might be subject to light-vehicle drivers cutting in between the platooning trucks, interrupting the constant speed and close-distance following required to optimize fuel efficiency (Lank, Haberstroh, and Wille 2011; Nodine et al. 2017).

Previous studies, including a feedback questionnaire and a behavioral study, indicate that drivers' knowledge of automated technology in the trucks may influence drivers' decisionmaking when interacting with these vehicles (Roldan and Gonzalez 2021). The behavioral study explored several options for identifying platooning activities and partially automated trucks and found that the presence of roadside and truck-mounted signs could positively influence light-vehicle drivers' understanding that the trucks were working cooperatively. These signs could also positively impact drivers' perceptions of the safety and predictability of platooned-truck movements (Roldan and Gonzalez 2021). The following study, designed using the University of Iowa's National Advanced Driving Simulator quarter-cab miniSim™ driving simulator, further investigated whether knowledge of partially automated truck platooning influences the behavior of light-vehicle drivers and whether truck-mounted signs, roadside messaging, or a combination of these elements are most beneficial to light-vehicle drivers. Additionally, changes in the behavior of light-vehicle drivers when encountering two standard-sized platooning trucks compared to three such trucks are unclear. In addition, the sheer size of a group of trucks traveling closely may pose a physical obstacle to light-vehicle drivers. Accordingly, this study also systematically evaluated the effects of platoon size (two or three trucks) and gap distance (0.6, 0.9, or 1.2 s) on driving behavior and driver perceptions.

OBJECTIVE

The primary objective of the study was to investigate how light-vehicle drivers' knowledge of partially automated truck platooning and how different platoon sizes (two- or three-truck platoon) and gap distances (0.6, 0.9, or 1.2 s) between the trucks influence the behavior of light-vehicle drivers entering, exiting, or traveling in the through lanes on the highway.

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APPROACH

The research team conducted two experiments in the miniSim driving simulator to assess light-vehicle drivers' behaviors: Experiment 1 evaluated the effects of truck platoon signing, and experiment 2 evaluated the effects of truck platoon configuration.

Experiment 1 assigned 48 participants to 1 of 4 experimental groups, which determined the types of signing participants would observe in the experiment (table 1). During the drive, participants completed a total of 18 trials on a simulated highway and encountered truck platoons at 6 predetermined intervals, including entering, exiting, and through areas. After the drive, participants completed a questionnaire regarding their perceptions of the simulated platoon. Participants were asked to rate on a five-point scale how safe they felt and assess the amount of required effort when driving near a pair of trucks. They were also asked open-ended questions regarding their reasoning behind the decision and their thoughts regarding the scenarios during the drive.

Experiment 2 assigned 36 new participants to 1 of 3 experimental groups, which were each exposed to different gap times between trucks in a platoon to evaluate whether and how different characteristics of truck platooning affect the behavior of light-vehicle drivers (table 2). During the drive, participants again completed a total of 18 trials on the same simulated highway but encountered 2- or 3-truck platoons (figure 1) at the 6 predetermined intervals while entering, exiting, and driving in through areas. After the drive, participants completed a questionnaire regarding their perceptions of the simulated platoons. Participants rated on a five-point scale how safe they felt and assessed the amount of needed effort when driving near a pair of trucks and a three-truck platoon. They were also asked open-ended questions regarding their reasoning behind the decision and their thoughts regarding the scenarios during the drive.

Figure 1. Illustration. Participants observed a two-truck platoon (left) and a three-truck platoon (right) during the driving simulator experiment.

Source: FHWA.

Table 2. Gap distance by group.

Group	Platoon Gap (s)
1	0.6
2	0.9
3	1.2

RESULTS

Experiment 1

The researchers did not find sufficient evidence in experiment 1 to show that signing had a significant influence on highway merging (entering) or exiting behavior. When entering the highway, most participants in all signage groups waited until the truck platoon passed. In the control/no sign group, 96 percent of drivers waited; in the roadside sign group, 79 percent of drivers waited; in the truck-mounted sign group, 92 percent of drivers waited; in the group presented with both roadside and truck-mounted signs, 100 percent of drivers waited. The data showed a similar tendency for drivers to wait before exiting the highway. In the control/no sign group, 96 percent of drivers waited until the truck platoon passed; in the roadside sign group, 88 percent of drivers waited; in the truck-mounted sign group, 83 percent of drivers waited; in the group presented with both roadside and truck-mounted signs, 96 percent of drivers waited.

Table 1. Sign type by group (Roldan and Gonzalez 2021).

Sign Type	Group 1	Group 2	Group 3	Group 4
Roadside-mounted	None		None	
Truck-mounted	None	None		

Source: FHWA.

Nevertheless, the researchers observed that participants exiting the highway were more likely to accelerate ahead of the truck platoons compared to when participants entered the highway, while cut-in behavior occurred more often when drivers entered the highway as compared to exiting. When driving on the through sections of the highway, participants who saw truck-mounted signs appeared to spend more time in the inner lane. The researchers assessed this behavior to be riskier because it introduced more lane-changing from the inner lane back to the outer lane when drivers were instructed to take the exit at the upcoming interchange. Although the effect of signing on driver lane choice was not statistically significant, participants in the roadside sign group spent more time in the outer lane than the other groups.

Questionnaire responses showed that participants who saw truck-mounted signs, especially drivers who saw signs on both the roadside and the truck, felt significantly more unsafe than participants who were not presented with any signage when driving on the exiting and through sections. Participants who saw either roadside signs or no signs reported feeling that driving took less effort compared to participants who saw truck-mounted signs, although the effect of signing on driving effort was not statistically significant. Some participants reported feeling uncomfortable when seeing or driving near trucks. Drivers' negative feelings could persist even after they observed a truck-mounted sign that provided information intended to reduce negative feelings.

The results of the experiment suggested that roadside signs might be a better option because they fostered relatively low-risk driving behavior (staying in the outer lane longer) and made driving seem safer and less effortful to participants.

Experiment 2

Results from experiment 2 showed that platoon size had a significant influence on participants' highway-merging behavior: A three-truck platoon could make drivers more prone to perform risky cut-ins ($p = .0012$). In addition, the researchers also observed that the longer the gap between the trucks in a platoon, the more likely that participants would perform risky cut-ins when merging onto the highway (although this is not statistically significant) (table 3). We did not observe cut-in behavior when participants exited the highway, but a few participants accelerated to move ahead of a truck platoon with shorter gap distances (table 3).

When driving on the through areas on the highway, participants generally spent more time in the inner lane when either a two-truck platoon with an 0.9-s gap distance or a three-truck platoon with an 0.6-s gap distance was present. The researchers deemed this tendency for drivers to stay in the inner lane as risky because it might introduce more lane-changing behaviors. Participants maintained a closer immediate-following distance to two-truck platoons compared to a three-truck platoon, although the difference was not statistically significant.

In the questionnaire section about drivers' perception of safety, participants generally reported slightly above average ratings in feeling safe when entering or exiting the highway and slightly below average ratings when driving in the through areas, regardless of the platoon gap and size. When asked about effort, participants reported that more effort was required when entering or exiting the highway and less effort was required in the through areas. The study also found that participants reported more effort was needed when a three-truck platoon appeared in the through lanes compared to a two-truck platoon. Overall, participants from all three gap groups reported that the truck-following distance was shorter than average. Several participants mentioned that the trucks were driving too close and that the platoons should have their own designated lane.

The results showed that no specific platoon configuration used in the context of this experiment could minimize risk in all areas on the highway at the same time. Although drivers might be tempted to cut in between a three-truck platoon with longer gaps during highway merging, they may also engage in more positive behavior, such as reducing lane changing or maintaining longer following distances behind the platoon. Participants also expressed

Table 3. Percentage of merge location for different conditions.

Platoon Gap	Platoon Size	Merge Location When Entering			Merge Location When Exiting		
		Behind	Between	Ahead	Behind	Between	Ahead
0.6 s	Two-truck	100	0	0	83	0	17
0.6 s	Three-truck	100	0	0	92	0	8
0.9 s	Two-truck	83	17	0	75	0	25
0.9 s	Three-truck	42	58	0	100	0	0
1.2 s	Two-truck	67	33	0	100	0	0
1.2 s	Three-truck	25	67	8	100	0	0

a feeling of being less safe in the through areas while simultaneously reporting such areas required less effort to drive. For this apparent contradiction, one reason might be that drivers had to interact with the truck platoon and other traffic in the area at the same time. As a result, while driving in the through areas might be less complicated than navigating the merging or exiting areas, people might feel unsafe when driving near a platoon along with other traffic.

CONCLUSION

Experiment 1 evaluated the effects of recommended signing with truck-platoon information on the roadside and on trucks to examine the signs' influences on light-vehicle drivers' behaviors. The findings suggest that roadside signs might be beneficial to drivers on a public highway. When using roadside signs to convey messages, coordinating with traffic management centers is needed, which entails an additional layer of effort; however, the use of roadside signs might be more economical since these signs can be integrated into the current transportation system that controls changeable message signs on the highway.

Experiment 2 evaluated the effects of truck platoon size and gap distance on light-vehicle drivers' behaviors. The results indicate that no specific platoon configuration used in the experiment could minimize risk in all areas on the simulated highway at the same time. The findings suggest that groups of trucks capable of self-configuring into different platoon sizes and adjusting the gap between trucks proactively based on current traffic conditions and highway sections, particularly in through areas, as opposed to remaining fixed or adjusting passively, would help light-vehicle drivers feel safe and help prevent risky behaviors. Drivers also might react differently to a platoon under different traffic conditions. Therefore, a follow-up study to investigate the effects of platoon configurations under different traffic conditions on light-vehicle drivers' perceptions and behaviors may be helpful. Additionally, an investigation incorporating a mixed-fleet environment under a more realistic scenario, possibly in a test-track environment, may further help establish effective practices for platoon operations. As automated truck platooning is expected to be commercially deployed in a mixed-fleet environment in the next several years, more human factors research related to light-vehicle drivers' behaviors and attitudes in the presence of truck platoons is needed to enhance roadway safety for all drivers.

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