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Effective Indicators of Partially Automated Truck Platooning

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INTRODUCTION

The development of automated trucking technology is progressing rapidly, and increasing numbers of on-road pilots suggest that full-scale commercial deployment of partially automated truck platoons on public roads is forthcoming.⁽¹⁾ In the United States, platoons typically consist of two to four trucks equipped with cooperative adaptive cruise control (CACC) to achieve close-distance following over long trips to yield fuel and cost savings.⁽²⁻⁴⁾ As widespread commercial deployment of automated trucking technology draws near, it is important to assess the potential effects of partially automated truck platoons on other road users. In addition to the novelty of partially automated vehicle operations, the sheer size of a group of trucks engaged in close-distance following may be a physical obstacle for—and pose safety concerns to—other road users. Supporting safe interactions between other road users and truck platoons also benefits platoons since nonplatoon vehicles cutting between or abruptly cutting off platooning trucks risks disrupting the constant-speed and close-distance following that is necessary for partially automated truck platoons to achieve financial and environmental benefits.

Despite the advanced progress in automated trucking and platooning technologies, the effects of truck platoons on other road users, and vice versa, remain unclear. Interactions between light and heavy vehicles have important implications for road safety as well as public acceptance of heavy truck automation. In addition to other drivers' potentially disruptive or risky behavior around truck platoons, the way in which road users perceive and respond to truck platoons is likely to influence societal trust in, and continued adoption of, similar automated driving technologies.

Given that most drivers of light vehicles will be unfamiliar with platooning technology during its early deployment, communicating information about truck platoon operations to surrounding road users may improve drivers' comfort and perceived safety near platoons, facilitate earlier and safer navigational planning, and discourage cut-ins between platooning trucks. However, standards regarding signing or indicators for automated vehicles and truck platoons have yet to be established. Therefore, this research effort first sought to identify terms and language that appropriately reflect platoon operations and characteristics. After identifying recognizable terms and essential platoon characteristics, the research team developed a set of four novel signs and indicators designed to support road user comprehension, comfort, and safety near truck platoons. A follow-up experiment evaluated the effectiveness of these novel signs and indicators in supporting road user comprehension and perceived safety of a simulated partially automated two-truck platoon.

RESEARCH

The research team conducted two experiments: one that evaluated how drivers label, perceive, and plan their behaviors around single and multiple trucks and another that evaluated the effect of novel signs and indicators on these judgements. Experiment 1 surveyed 50 participants to determine how drivers describe and respond to single and grouped conventionally driven trucks. The survey also explored participants' attitudes regarding conventionally driven and partially automated truck platoons.

Experiment 2 presented 48 new participants with static simulated scenarios of a two-truck platoon with and without novel signs and indicators developed from the findings of experiment 1 (table 1). All participants in experiment 2 first viewed and answered questions regarding four scenarios without signs or indicators (i.e., the control condition). Next, participants viewed the same four scenarios with one set of novel signs or an indicator, as seen in figure 1, according to the group condition listed in table 1. The research team evaluated the effects of the novel signs and indicators on participant judgements regarding navigation around the trucks, safety, and expectations for platoon operations.

RESULTS

Experiment 1

In experiment 1, 54 percent of survey respondents associated driving near or around single heavy trucks with negative feelings like anxiety or fear and 44 percent described having neutral reactions, sometimes stating caution or awareness. Most participants (91 percent) reported they drive differently around trucks compared to other passenger vehicles.

The survey also revealed that drivers' experiences with conventionally driven trucks biased them to expect trucks to operate independent of one another and even competitively, thus leading them to see trucks—especially those following other vehicles at short distances—as potential aggressors. Respondents indicated they determined whether trucks were intentionally following one another by considering the spacing between the trucks, whether the trucks were in inner or outer travel lanes, and the branding or markings on the trucks. Participants' ratings of truck and other road user safety decreased significantly ($p < 0.0001$) across three photographs depicting two or more trucks traveling with increasingly shorter following gaps.

The term "platoon," although widely used in the transportation industry to describe groups of partially automated trucks, was neither familiar nor readily understood by participants. Instead, most participants (72 percent) chose "convoy" when asked to select a term from a predefined list to label a group of partially automated (CACC) trucks (figure 2). The term "linked" was most frequently selected (29 percent) to describe a single automated truck operating within a group of other automated trucks.

In 16 percent of survey responses, participants noted that, because truck platoons would be expected to remain in a consistent formation and lane for an extended duration of time, they would be more predictable and thus safer and more comfortable to travel near than conventionally driven trucks. Out of four statements conveying truck platoon status or location, the majority of participants ranked awareness of the trucks' active engagement in automated platooning as most important, followed by highways/roads where

Table 1. Sign and indicator stimuli used in experiment 2.

Sign Type	Group 1	Group 2	Group 3	Group 4
Roadside-mounted	R1 	R2 	R3 	None
Truck-mounted	T1 	T2 	T3 	Light bar 

All photos source: FHWA.

Note: Each group consisted of 12 participants.

Figure 1. Screenshots. Progression of scenarios for signs R1 and T1 from experiment 2.



Source: FHWA.

A. Beginning of entrance ramp (sign R1).



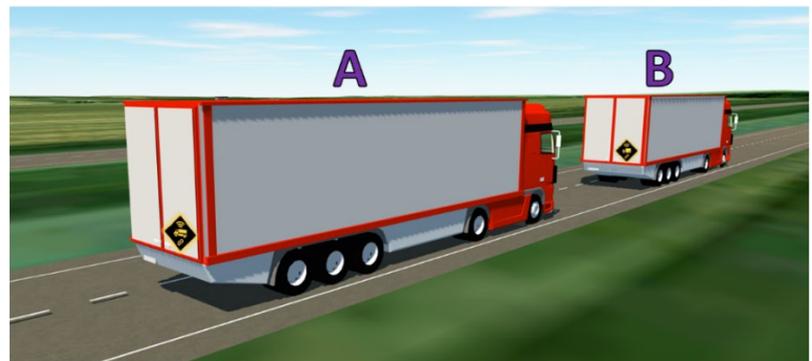
Source: FHWA.

B. Merging onto the highway (sign T1).



Source: FHWA.

C. Approaching an assigned exit (sign T1).



Source: FHWA.

D. Wide side view of trucks (sign T1).

trucks may be platooning, the number of trucks in the platoon, and the exact location of the truck platoon. The research team applied these findings when selecting content, wording, and intended messaging for the novel signs and indicators evaluated in experiment 2.

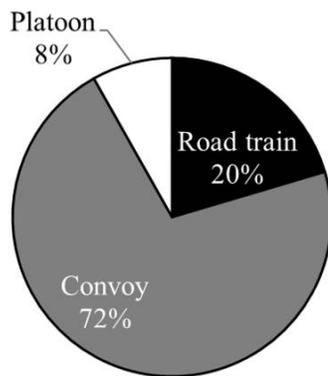
Experiment 2

Results from experiment 2 showed that the presence and type of signs or indicators indeed influenced participants' understanding of truck platoon operations. When viewing control scenarios in which the simulated truck platoon was presented without additional signs or indicators, less than 20 percent of participants expected the unsigned trucks to execute lane-change maneuvers in tandem. However, this pattern reversed when a pair of signs or an indicator was included in the scenario, such that over 60 percent of participants within each group expected the rear truck to follow the lead truck into the left lane. In addition, operational and personal safety ratings were consistently higher for scenarios that included novel signs or indicators stimuli compared to those without. Unexpectedly, although all the novel signs and indicators increased participants'

expectations that the trucks would follow one another when compared to unsigned scenarios, trucks presented with signs using the term "convoy" were less likely to be thought of as "cooperative" when compared to trucks presented with other signs or indicators. Participants indicated this expectation may be due to "convoy" being strongly associated with conventionally driven trucks.

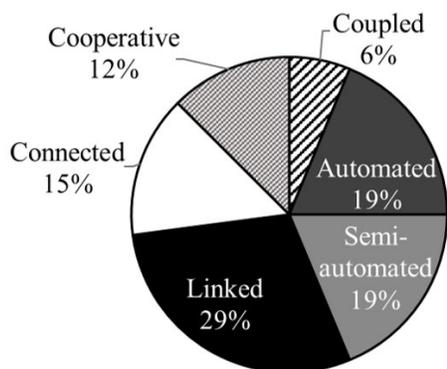
Signs and indicators also influenced participants' understanding of grouped close-distance following among trucks, awareness of the use of connected or automated technologies, and willingness to cut-in between the trucks. Compared to other signing options presented, the light bar was least successful at conveying truck platoon operations and was instead interpreted as a general warning. Overall, group 2's combination of roadside-mounted and truck-mounted signs (i.e., signs R2 and T2) identifying the platoon as a "linked convoy" performed highest on comprehension of grouped close-distance following and perceived personal and operational safety. In addition, signs R2 and T2 had the greatest legibility distances of the roadside- and truck-mounted sign types, and

Figure 2. Pie Charts. Distribution from experiment 1 of terms selected to describe grouped or individual automated trucks.



Source: FHWA.

A. Group of automated trucks.



Source: FHWA.

B. Individual automated trucks.

participants rated these signs as most preferred and effective among the seven novel signs and indicators tested.

The results of the experiment provide evidence that signs or indicators influence drivers' perceptions of trucks' operations and the relationship between them. Although the mere appearance of two trucks with short following gaps may suggest close-distance following, the results of the experiments showed that short following gaps alone were not sufficient to imply intentional cooperative following. In experiment 2, participants were notably more likely to expect trucks to execute lane maneuvers in tandem when presented with a sign or indicator compared to control scenarios. In addition, perceived operational and personal safety ratings were consistently lower for unsigned trucks compared to trucks presented with a light bar or set of novel signs. In fact, the highest ratings of perceived personal and operational safety were associated with signs R2 and T2.

CONCLUSION

The results of both experiments provided evidence that using signs to identify automated truck platoons may be an effective method for supporting driver comprehension, safety, and acceptance of heavy-truck automation. In addition, the signs developed for experiment 2 demonstrate a range of potential options for facilitating road user understanding of various truck platooning operations. Future work will involve evaluating signs R2 and T2 in a driving simulator scenario that involves participants entering and exiting a freeway near a partially automated two-truck platoon. The experiment will further explore drivers' reactions to signed and unsigned platoons and investigate the relative value of roadside- and truck-mounted signs appearing in tandem or individually.

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