Cooperative Truck Platooning on Canadian Public Roads during a Winter Season

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Abstract. Cooperative truck platooning, electronically linking two or more trucks in convoys, holds great potential for improving energy efficiency, reducing vehicle emissions, and enhancing traffic safety. However, conducting commercially focused truck platooning operations in real-world winter driving conditions poses significant challenges. This study presents the experimental results of a pioneering truck platooning trial conducted on Canadian public roads. Two Class 8 heavy-duty trucks equipped with cooperative truck platooning systems (CTPS) classified as SAE Level 2 automation were used in the trial. A total of 41 CTPS trips were carried out on Alberta Highway 2 between Calgary and Edmonton during the winter season at ambient temperatures ranging from -27 to 12 °C, while the weight of each truck varied from 16 to 39 ton. The outcomes of these experiments provided conclusive evidence supporting the feasibility of implementing CTPS with time gaps ranging from 3 to 5 seconds on public roads during winter seasons. The average platooning engagement ratio, accounting for 4 road surface conditions, reached 60.7%, with the maximum engagement ratio peaking at an impressive 96.0%. Moreover, it was observed that on flat roads, the fuel consumption of the follower truck in the platoon reduced by an average of 5.8%, while on hilly terrain, there was an average increase of 10.7%. The traffic interactions of cut-ins and cut-outs resulted in the follower truck consuming an average of 20.6% more fuel compared to the lead truck. This study enhances the understanding of implementing truck platooning in commercial operations under the winter driving conditions.

Keywords: Cooperative Truck Platooning, Commercial Operation, Winter Season, Road Grades, Traffic Interactions.

1 Introduction

Trucking plays a vital role in freight shipping in Canada, which accounts for up to 70% of the domestic freight transportation. It is therefore a crucial pillar of Canada's economy, where the trucking industry contributed approximately $40 billion in 2021 [1]. However, it is important to address the environmental impact of the trucking industry, especially in terms of energy consumption and greenhouse gas (GHG) emissions. While ongoing research focuses on improving energy efficiency and reducing exhaust emissions through propulsion system and vehicle design advancements, a promising approach is cooperative truck platooning, which allows two or more trucks to travel in close proximity while communicating with each other in real-time. In addition to the potential energy and emissions benefits, truck platooning also offers advantages in terms of traffic safety [2-4] and roadway capacity [5-7]. As a result, researchers worldwide have devoted significant efforts to explore and harness the potential benefits of truck platooning.

Numerous research projects and trials has been conducted globally to verify the feasibility and investigate the impact of truck platooning. The European project Promote Chauffeur I was the first study on truck platooning, where two heavy-duty trucks adopted the “Electronic Tow Bar” technology to get coupled. The tests took place on a level test track and resulted in a 21% reduction in fuel consumption at a spacing of 10 meters [8]. The project Promote Chauffeur II was followed, and its work focused on developing advanced driver assistance systems to safely shorten the following distance [9]. In Germany, the national project KONVOI was carried out to investigate the impact of platoons consisting of four heavy-duty trucks on motorways under real traffic scenarios. This project examined not only the technical aspects but also the legal and economic implications [10]. Another European project, SARTRE, demonstrated a platoon that included both trucks and passenger cars on motorways, maintaining a gap of approximately 6 meters between the platooning vehicles [11]. More recently, the ENSEMBLE project aimed to facilitate Europe-wide deployment of multi-brand truck platooning, showcasing platoons consisting of up to seven trucks from different manufacturers in real-world traffic conditions [12]. The first known truck platooning project in the USA was launched under the California Partners for Advanced Transit and Highways (PATH) program. Through this initiative, it was found that two tandem trucks achieved average fuel consumption savings ranging from about 8% to 11% at spacing distances of 3-10 meters [13]. Additionally, Canada collaborated with the USA to examine the fuel-saving impact of truck platooning, revealing that the net fuel savings for a three-vehicle truck platoon ranged between 5.2% and 7.8% [14]. Canada also conducted its first cooperative truck platooning trial in 2018, using two SAE Level 1 trucks. Although fuel savings were not measured during this trial, it served as an important step in understanding truck platooning in different road conditions, including on-road and off-road portions [15]. The projects mentioned above represent some of the prominent initiatives in truck platooning, but they are just a fraction of the extensive research and trials taking place worldwide. A number of truck platooning projects have been and continue to be carried out in Europe, USA, Japan, Canada, China, South Korea, Australia, Singapore, and others.

The presented results from international studies have demonstrated the potential of truck platooning in achieving fuel reduction. However, it is important to note that most of the automation systems employed in these projects were limited to longitudinal control only, corresponding to SAE Level 1 automation. Additionally, there is a notable scarcity of studies conducted on public roads under real commercial operations, especially in challenging winter driving conditions characterized by extreme cold weather and varying road surfaces. To address these gaps, the present study undertook the first-of-its-kind cooperative truck platooning system (CTPS) trials with two SAE Level 2 trucks. The main objective was to assess the performance of truck platooning under the real commercial conditions in typical Canadian winter season. A total of 41 CTPS trips were carried out on Alberta Highway 2 between Calgary and Edmonton during the winter season in January 2022.

The remainder of this paper is organized as follows. Section 2 provides an overview of the cooperative truck platooning system and describes the data collection methodology employed for the CTPS trials. The test results obtained from the conducted platooning trips are presented in Section 3. Finally, Section 4 concludes the study by summarizing the key findings and implications.

2 Cooperative Truck Platooning System and Data Collection

In this work, the cooperative truck platooning systems were installed in two Class 8 heavy-duty trucks to conduct the platoon tests with 3 to 5 sec time gaps. The CTPS technology encompassed a range of components, including radar, cameras, global positioning system (GPS), vehicle-to-vehicle communication, and various equipment, as illustrated in Figure 1. The GPS system provided precise positioning information for the trucks, while the long-term evolution (LTE) antenna facilitated communication and the exchange of vital platooning-related data between the two vehicles, enabling coordinated maneuvers and actions. The forward-facing camera mounted on the windshield was responsible for detecting vehicles and lane markings, whereas a driver-facing camera was employed to monitor the driver's attentiveness. Additionally, a radar system installed in the front bumper enabled the detection of vehicles ahead and measurement of the distance between the truck and other vehicles. To ensure accurate estimation of the gap between the two trucks, sensor fusion techniques were applied, combining data from the forward-facing camera and the radar system. Moreover, the system is capable of seamlessly integrating with the truck's throttle and steering controls through the implementation of drive-by-wire technology. This allows for precise manipulation of the steering angle and throttle position to achieve the desired outcomes. According to the SAE J3016 standard [16], the trucks equipped with CTPS were classified as SAE Level 2 automation.

Fig. 1. Equipment and sensors used in cooperative truck platooning.

To ensure the collection of high-frequency and synchronized data, a custom-designed integrated central data acquisition system (ICEDAQ) was developed specifically for this study. The ICEDAQ system incorporated various essential features, including robust data protection mechanisms, remote live monitoring capabilities, and the ability to record multiple data streams simultaneously. These functionalities were instrumental in maintaining the integrity and security of the collected data while enabling real-time monitoring of the system from remote locations. The implementation of the ICEDAQ system played a crucial role in facilitating a comprehensive assessment of the performance of truck platooning. In total, an extensive dataset over 1TB comprising 339 parameters sourced from over 10 different sensors was collected for both trucks.

3 Test Results

In total, 41 trips using the CTPS were carried out on Alberta Highway 2, spanning the route between Calgary and Edmonton. These trips took place during the winter season in January 2022, with ambient temperatures varying from -27 to 12 °C. Out of the 41 trips, 28 trips were designated for platoon tests. The platooning systems were activated exclusively outside the city limits, specifically between Airdrie and Leduc, covering a distance of 234 km.

3.1 Platoon Engagement Ratio

The platoon engagement ratio was determined by dividing the platoon engagement "time" by the duration of each platooning trip between Airdrie and Leduc. Figure 2 illustrates that, under dry surface conditions, the platoon engagement ratio ranged from 4.0% to 88.9%, with an average ratio of 59.9%. When considering wet surface conditions, the platoon engagement ratio varied from 40.7% to 96.0%, with an average ratio of 62.5%. Moreover, for road conditions involving partly covered snow and shoulder ice/snow, the average platoon engagement ratios were 59.0% and 66.1%, respectively. When all road surface conditions were taken into account, the average platooning engagement ratio across all trips amounted to 60.7%.

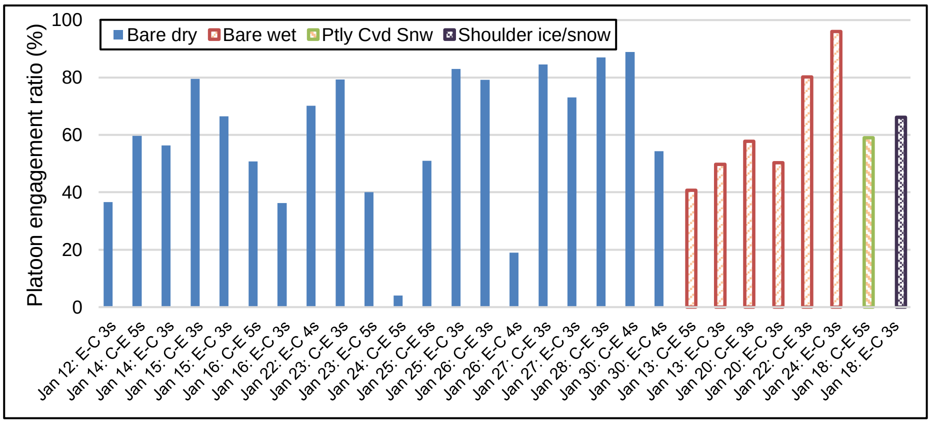

Fig. 2. Platoon engagement ratio under four different road surface conditions.

3.2 Platooning Fuel Consumption

To enable a proper comparison, the accumulative fuel consumption values were normalized based on the weights of the trucks, known as freight transportation specific fuel consumption[1]. As illustrated in Figure 3, the lead truck (AB1) exhibited a specific fuel consumption ranging from 0.54 to 1.36 kg/(ton·100km), whereas the follower truck (AB2) demonstrated a range of 0.50 to 1.54 kg/(ton·100km). Furthermore, for heavy configurations surpassing 30 tons, the specific fuel consumption approached approximately 0.65 kg/(ton·100km). Tests conducted on both trucks under non-platooning conditions, where the separation gap exceeded 1 km, revealed that, on average, the lead truck consumed 8.3% more fuel than the follower truck. This suggests that, during platooning, the follower truck generally exhibited higher specific fuel consumption compared to the lead truck. This observation can be attributed to the considerable time gaps (i.e., ≥ 3s) between the lead and follower trucks during platooning trips, where the aerodynamic drag reduction benefits were not substantial under this study's settings. Additionally, factors such as traffic interactions and road grades contributed to greater engine power fluctuations in the follower truck, leading to increased specific fuel consumption.

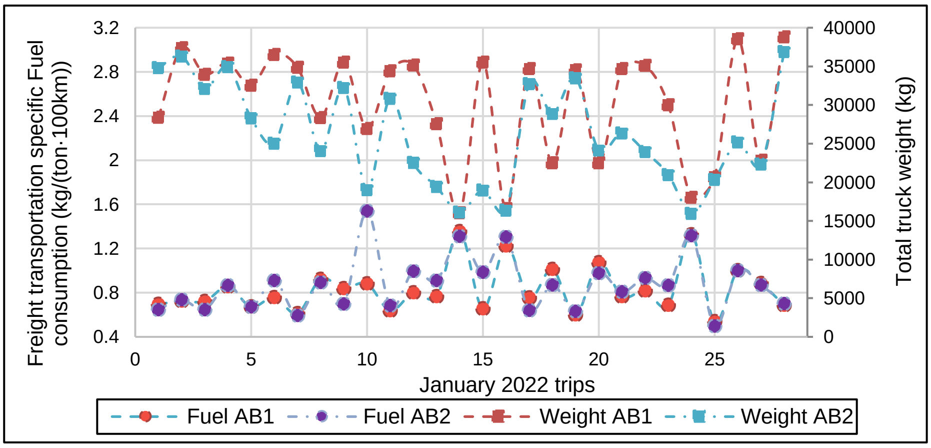

Fig. 3. Freight transportation specific fuel consumption of lead and follower trucks during platooning.

3.3 Platooning Time Gap

Time gap refers to the amount of time between two consecutive trucks passing through a given point during a trip. The road geometries exerted a significant influence on platooning time gaps. As shown in Figure 4, when the road sections were flat, the average time gap error amounted to 0.55 sec; it increased to 0.79 sec when encountering the downhill road sections and further rose to 0.81 sec when the road sections featured

[1] Freight transportation specific fuel consumption is determined by dividing the fuel consumption (in kg/100 km) by the gross weight of the truck (in ton).

substantial uphill slopes. Despite an approximate 0.72-sec discrepancy between the commanded and actual time gaps on various road conditions (including flat, downhill, and uphill sections), the cooperative truck platooning systems consistently maintained a safe distance between the trucks throughout the platooning operation.

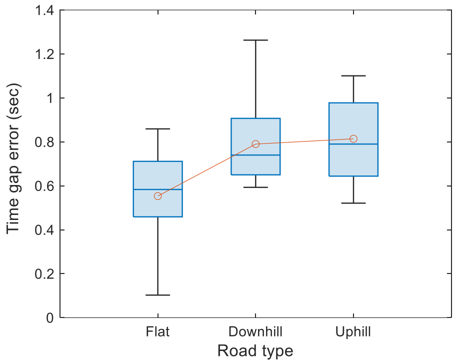

Fig. 4. Time gap errors between lead and follower trucks under different road geometries.

3.4 Effects of Road Geometry on Fuel Consumption of Platooning Truck

Five trips were selected on a flat road segment with a grade ranging from -0.1% to 0.1%, during which the two trucks operated in platoon mode. Table 1 presents the fuel saving ratio of the follower truck compared to the lead truck for each trip on this particular road segment. The follower truck achieved fuel savings in all five trips, with an average fuel saving ratio of 5.8% on the flat road segment.

Similarly, for a road section on Highway 2 characterized by relatively steep grades ranging from -5.6% to 4.5%, five trips were selected where the two trucks maintained continuous platooning. Table 1 provides the fuel saving ratios of the follower truck for these trips. The follower truck's fuel saving ratio varied from -20.4% to -0.9%, with an average fuel saving ratio of -10.7% on this road segment with grade variations. The impact of hilly terrain on the fuel consumption of the follower truck in a platoon was more significant compared to that of a flat road.

Table 1. Follower truck's fuel saving ratio under different road geometries.

Trip #	Flat Road (%)	Hilly Road (%)
1	0.5	-15.0
2	0.1	-14.0
3	9.2	-0.9
4	12.0	-20.4
5	7.2	-3.1
Average	5.8	-10.7

*Fuel saving ratio with a minus sign indicates an increase in fuel consumption.

3.5 Effects of Traffic Interaction on Fuel Consumption of Platooning Truck

During truck platooning operations, common traffic interactions involved cut-ins and cut-outs, which typically occurred when vehicles entered or exited the highway at on-ramps or off-ramps, as well as during lane-changing maneuvers by other vehicles. It was observed that as the time gap increased from 3 to 5 seconds, the frequency of cut-in events increased from 1.6 to 5 times per hour. Figure 5 provides insights into the follower truck's fuel consumption ratio in different types of cut-in and cut-out scenarios. The fuel consumption ratios for lane-changing maneuvers varied between 0.6% and 92.5%, with an average of 21.2%. These variations can be attributed to the specific locations of the cut-ins. Notably, the average fuel consumption ratio for off-ramp cut-ins and cut-outs (29.2%) was more than double that of on-ramp cut-ins and cut-outs (12.2%). This discrepancy arises from the deceleration of vehicles during off-ramp maneuvers and the acceleration observed during on-ramp maneuvers.

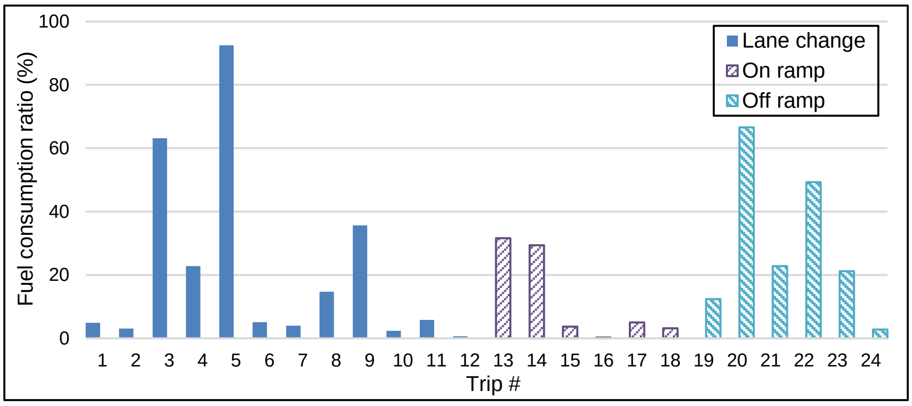

Fig. 5. Follower truck's fuel consumption ratio under the cut-ins and cut-outs maneuvers of lane changing, on ramp and off ramp.

4 Conclusion

The first-of-its-kind CTPS trials were conducted under various driving conditions to assess the feasibility of implementing truck platooning in a commercial setting under Canadian winter climate conditions. The trials covered a total distance of 22,855 km and provided valuable insights into the performance of cooperative truck platooning. The results demonstrated that truck platooning could be safely implemented, with platooning engagement ratios reaching up to 96%, and an average engagement ratio of 60.7% across four different road surface conditions. However, it is important to note that the investigated platform did not yield substantial fuel-saving benefits during the cold winter season under commercial operation. The trials also shed light on the influence of road grades on the performance of truck platooning. The results revealed that on flat roads, the fuel consumption for the follower truck was reduced by an average of 5.8%. However, on hilly terrain, the follower truck experienced an average increase in fuel consumption of 10.7%. An average time gap error of 0.55 sec was observed on the flat road, with larger errors occurring when encountering road grade changes. Furthermore, the fuel consumption ratios of the follower truck varied for different traffic scenarios. Specifically, the average fuel consumption ratios for lane changing, on-ramp, and off-ramp were 21.2%, 12.2%, and 29.2%, respectively.

The CTPS trials conducted on the Canadian public roads have provided compelling evidence of the viability of truck platooning in commercial settings under winter driving conditions. However, to enhance the practical utility of CTPS, certain areas of improvement can be explored. Firstly, optimizing the time gap setting can effectively reduce the occurrences of cut-ins by other vehicles, thereby positively impacting the platoon engagement ratio and fuel consumption. Secondly, developing a platoon control system that can optimize fuel consumption based on varying road grades would further enhance the performance of CTPS.

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