Evaluating Traffic Efficiency and Safety by Varying Truck Platoon Characteristics in a Critical Traffic Situation

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ToGRIP

GRIP on Freight Trips

Introduction

- Truck platooning is the application of cooperative adaptive cruise control where multiple trucks are electronically linked using V2V communication.
- Truck platoons might bring fuel savings and emission reductions. However, their interactions with surrounding traffic and resulting impact on traffic operations and safety are not fully understood.
- Research is needed to assess the impacts of truck platoons especially in critical traffic situations. One of these situations lies around merging sections.

Research objective

- To evaluate the effects of varying truck platoon characteristics on traffic efficiency and safety around a merging section

Modeling of truck platoons

Longitudinal controller

- ***Preliminaries***

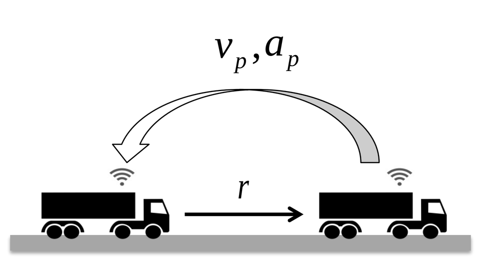
$$r^{\text{safe}}_{\text{mode}} = t^{\text{system}}_{\text{mode}} \cdot v + r_{\text{standstill}} \qquad \forall \quad \text{mode} \in \{\text{CACC}, \text{ACC}\}$$

- ***Cooperative Adaptive Cruise Control (CACC)***

$$a^{\text{ego}}_{\text{CACC}} = k \cdot (v_{\text{des}} - v) + k_d \cdot (r - r^{\text{safe}}_{\text{CACC}})$$

$$a^{\text{lead}}_{\text{CACC}} = k_a \cdot a_p + k_v \cdot (v_p - v) + k_d \cdot (r - r^{\text{safe}}_{\text{CACC}})$$

$$a_{\text{CACC}} = \begin{cases} \min(a_{\max}, \max(a^{\text{lead}}_{\text{CACC}}, a_{\min})) & \text{if } a_p > 0 \\ \min(a_{\max}, \max(\min(a^{\text{ego}}_{\text{CACC}}, a^{\text{lead}}_{\text{CACC}}), a_{\min})) & \text{otherwise} \end{cases}$$



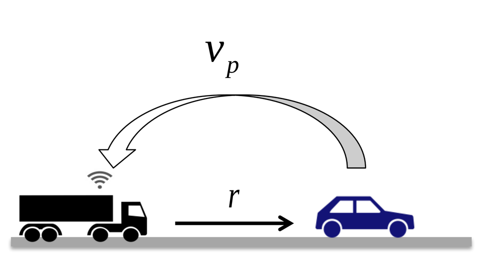
Ego truck

- ***Adaptive Cruise Control (ACC)***

$$a^{\text{ego}}_{\text{ACC}} = k \cdot (v_{\text{des}} - v) + k_d \cdot (r - r^{\text{safe}}_{\text{ACC}})$$

$$a^{\text{lead}}_{\text{ACC}} = k_v \cdot (v_p - v) + k_d \cdot (r - r^{\text{safe}}_{\text{ACC}})$$

$$a_{\text{ACC}} = \min(a_{\max}, \max(\min(a^{\text{ego}}_{\text{ACC}}, a^{\text{lead}}_{\text{ACC}}), a_{\min}))$$

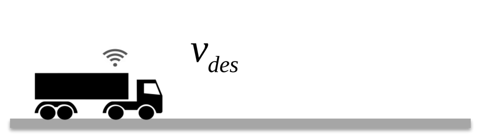


Ego truck

- ***Cruise Control (CC)***

$$a^{\text{ego}}_{\text{CC}} = k \cdot (v_{\text{des}} - v)$$

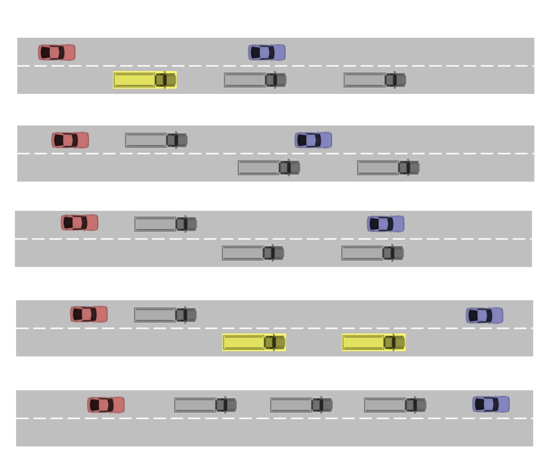
$$a_{\text{CC}} = \min(a_{\max}, \max(a^{\text{ego}}_{\text{CC}}, a_{\min}))$$



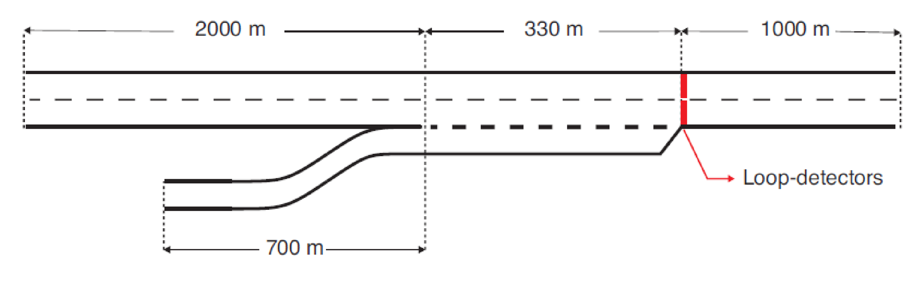
Ego truck

Lane changing controller

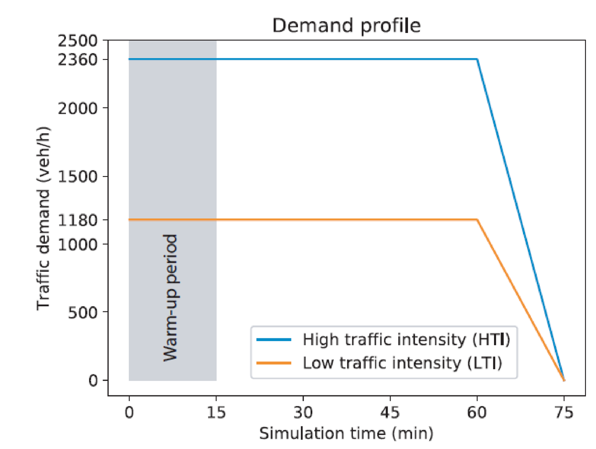
- Last-vehicle first principle
- Last vehicle in a platoon starts blinker and changes lane first
- Rest of vehicles in a platoon change lanes
- Trucks in a platoon may also decelerate to shorten the lane changing process
  - Gap-creation deceleration



Experimental design



Interchange Benelux on A15, The Netherlands



Microscopic traffic simulator

- OpenTrafficSim
- Java-based which uses IDM+ and LMRS

OTS

- Trucks: 15%
- On-ramp demand is 25% of mainline demand

Scenarios

- **Base case**: No platoons
- **Scenario 1**: Truck platoons on mainline carriageway
- **Scenario 2**: Truck platoons merging onto mainline carriageway

Indicators

Efficiency	Safety
Average travel time (TT)	Time to collision (TTC<4s)
Maximum flow (Flow)	Req. Braking rate (RBR<-2.1m/s²)

Impact of reference platoon configuration

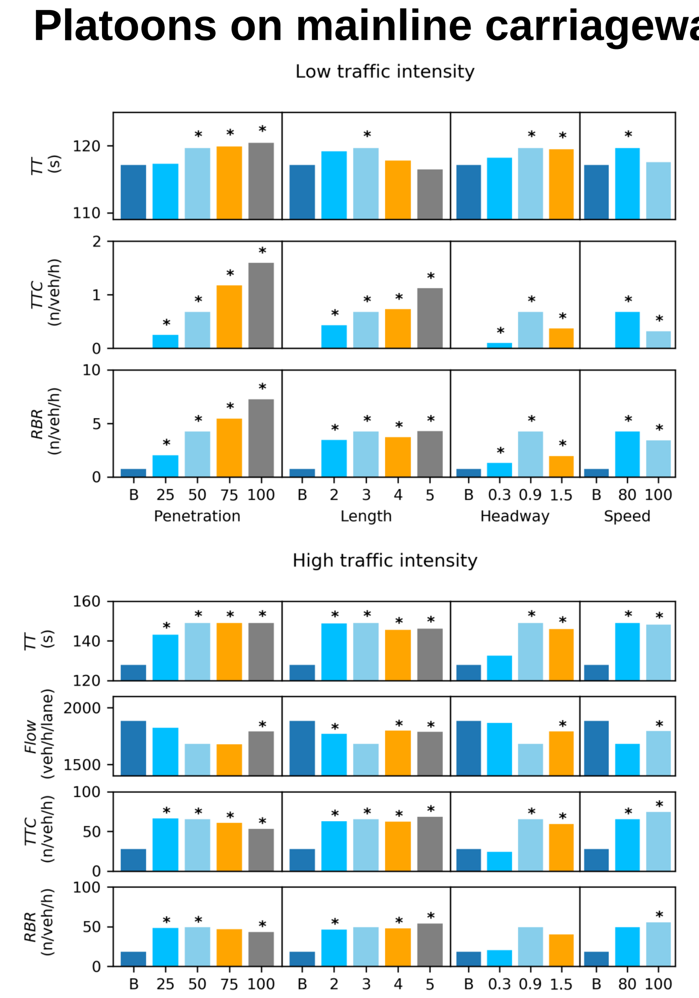
Platoon characteristics

- **Market penetration rate**: 0% (Base case), 25%, **50%**, 75%, and 100%.
- **Platoon length**: 2 trucks, **3 trucks**, 4 trucks, and 5 trucks.
- **Headway in a platoon**: 0.3 s, **0.9 s**, and 1.5 s.
- **Desired platoon speed**: **80 km/h** and 100 km/h.
- **Gap-creation deceleration**: **0 m/s² (off)**, 1.5 m/s², and 3.0 m/s²
- **Lane changing**: only mandatory lane changing is allowed
- **Cut-ins**: only if intra-platoon headway allows for that

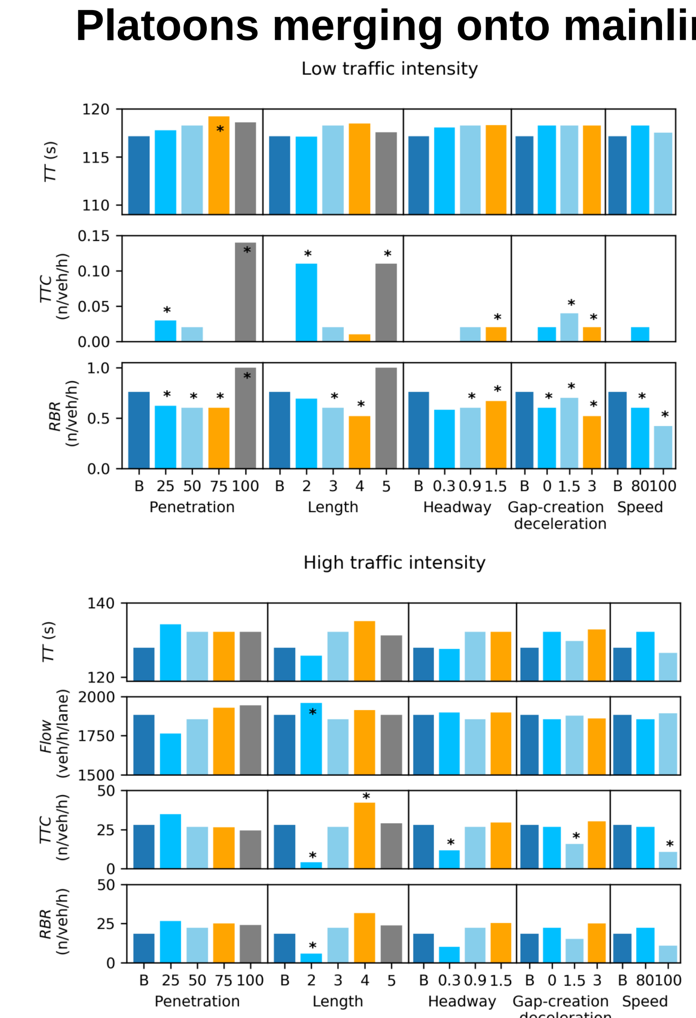
Scenario	TT (s)	Flow (v/h/l)	TTC (n/v/h)	RBR (n/v/h)
Low traffic intensity				
Base case (no platoons)	117.12	-	0.00	0.76
Reference platoon on mainline carriageway	**119.65**	-	**0.68**	**4.25**
Reference platoon merging onto mainline	117.51	-	**0.02**	**0.60**
High traffic intensity				
Base case (no platoons)	127.93	1884	27.95	18.44
Reference platoon on mainline carriageway	**149.04**	**1682**	**65.40**	**49.01**
Reference platoon merging onto mainline	132.16	1854	26.72	22.17

Local (one-at-a-time) sensitivity analysis

Platoons on mainline carriageway



Platoons merging onto mainline

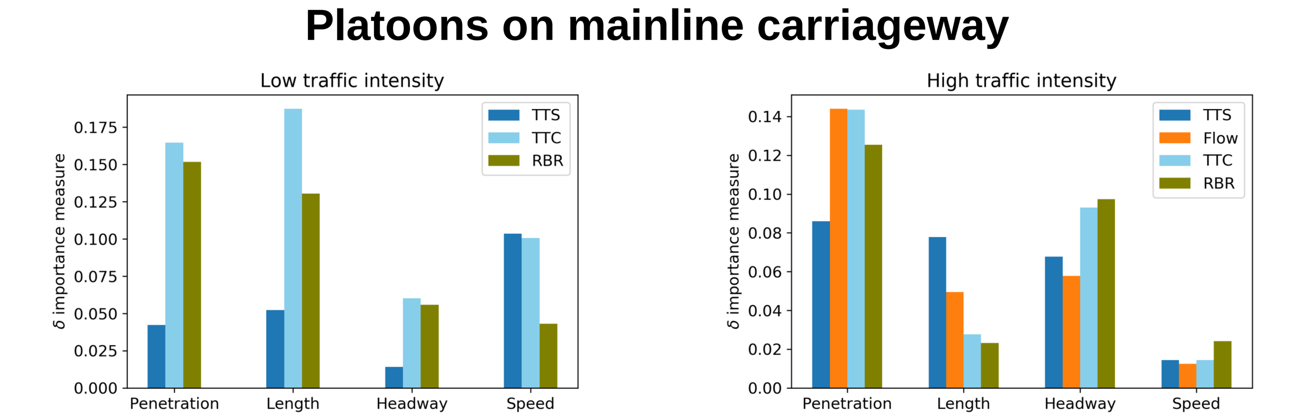


- We change one characteristic of a platoon at a time by keeping others fixed at reference configuration and observe its effect on the output.
- Useful to select some of the best performing platoon configurations in a situation

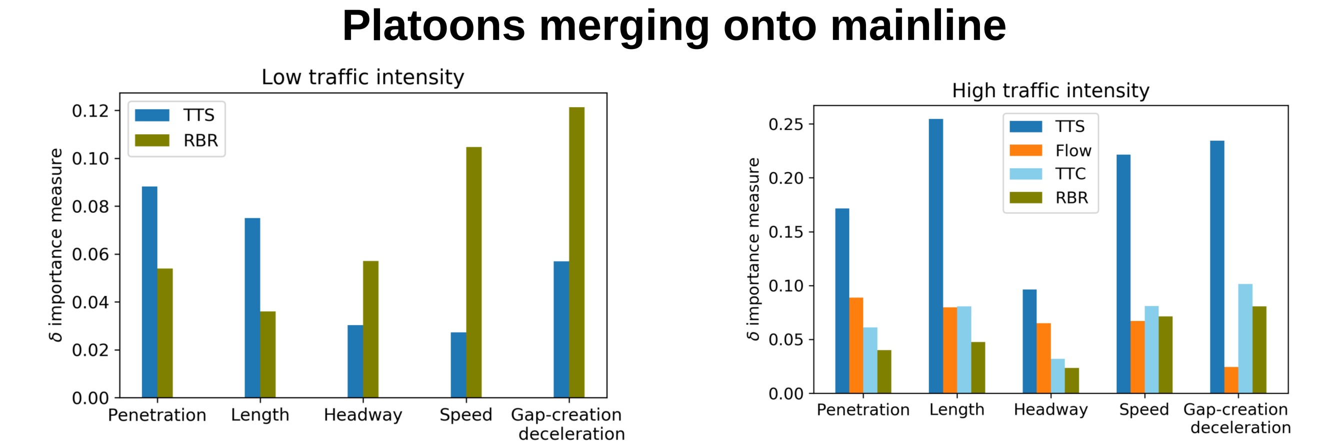
Global sensitivity analysis

- Latin-hypercube sampling is used to generate full design space.
- Moment-independent measure (δ) technique is used to quantify the uncertainty in output/indicators.
- Higher the value of δ_i, the higher will be the effect of input i on output.
- Interactions between platoon characteristics play a major role in output uncertainty.

Platoons on mainline carriageway



Platoons merging onto mainline



Conclusions

- **Truck platooning on the mainline carriageway seems to be detrimental to traffic efficiency and safety in high traffic intensity.**
- **Truck platoons merging onto mainline carriageway has limited effects on traffic efficiency and safety.**
- **Uncertainty in traffic efficiency and safety strongly depends on the interactions among platoon characteristics, traffic demand, and considered traffic scenarios.**

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