DTU Library

Intelligent truck platooning: how to make it work

Rich, Jeppe; Larsen, Rune; Rasmussen, Thomas Kjær

[Link back to DTU Orbit](#)

Intelligent truck platooning: how to make it work

Jeppe Rich [1*], Rune Larsen [1], Thomas Kjær Rasmussen [1]

[1] DTU Management Engineering, Technical University of Denmark, Bygningstorvet 116B, 2800 Kgs. Lyngby, Denmark
[*] rich@dtu.dk

Abstract: Platooning of trucks is a means to improve efficiency in the road transportation of goods. Truck platooning can lead to fuel savings in the order of 5-10%, but may also yield substantially larger benefits by, fully or partially, obviating drivers. This may be possible in situations where drivers, who engage in platooning activities, can rest while they are not the leading truck. In this paper we argue that forming truck platoons is unlikely to be successful if based on an 'on-the-fly' principle. Rather, a system of "platooning-stations" is required for forming platoons off the road. In the paper we propose a simple greedy-algorithm and subsequent local search for achieving locally optimal platoons at such stations. The solution reflects an optimisation of shared mileage among members of each platoon and is solved in discrete time-steps at each station. As a final contribution, we investigate the potential of the proposed algorithm in a real-world case by investigating platoon formation under a variety of circumstances for an artificial platooning station located close the Elb-tunnel. More specifically, we consider the generated route-path of 1500 trucks crossing this location and calculate optimal solutions for a variety of different design criteria's.

1. Introduction

Truck platooning involve the grouping of trucks into connected sequences of trucks in order to save fuel, and at later stages in the forthcoming ITS revolution of autonomy, relax rest hour restrictions. Truck platooning is not a new technology. It has been researched and debated since the 1940s (Geddes, 1940[1]) and in the last three decades resulted in numerous proof of concept projects and demonstration projects (Stevens 2015[2]; Benz et al. 1996[3]; Frits et al. 2004[4]; The European Truck Platooning Challenge 2016[5]). The main focus has been on technological aspects of platooning and how vehicle-to-vehicle communication and sensor technology can be applied to facilitate platooning (Bergenhem et al. 2012[6]). Along these lines mathematical models for platooning control and optimal stability have been developed (e.g, Serban et al., 2017[7]) and adaptive cruise control manoeuvres (Nowakowski et al., 2015[8]) and it is today clear that the platooning technology exist and it close to be fully operational in real-world applications (Janssen et al., 2015[9]).

Clearly, there are still remaining technological challenges as to how trucks will and should operate in mixed traffic conditions and how intersections may affect platoons, however, the fundamental technological basis is today no longer the main issue (Stevens et al. 2014[10]). Rather, the main challenge of today is related to the practical implementation of such systems, the interaction with the physical infrastructure and the possible impact in terms of safety, security and operationalisation.

The European Truck Platooning Challenge 2016, which is an initiative of the Dutch Ministry of Infrastructure and the Environment, has in a recent report considered the important challenges of platooning (European Truck Platooning, 2016[5]). It is interesting to note that they consider the maintaining and re-forming of truck platoons as a significant challenge, however, they do not consider the initial formation stages of truck platoons. Similarly, in a recent technology road-map concerning design challenges for different platooning systems (Misener and Zhang, 2015[11]) there is no mentioning of the challenge of forming platoons. Hence, based on a substantial part of the literature it seems as if the initial forming of platoons is either trivial or irrelevant from a planning perspective. However, this viewpoint conflict with Mallozzi et al. (2016[11]) and Bergenhem et al. (2010[13]) who argue that formation and joining stages are recognised as critical stages.

In the literature as well as in the practical logistical world there seems to be a general implicit understanding that platooning can either take place as "on-the-fly" platoonings (Janssen et al., 2015[9]) or as part of a pre-planning stage, which involve a longer prediction horizon. The first case resemble a situation where trucks go on the motorway and engage in platoons with the first truck available without any pre-planning stages. However, it is has been argued early in Hall and Chin (2005[14]) that it is better to form platoons before the trucks enter the high-way system. Moreover, the idea that platooning can be performed on the highway system as an "on-the-fly" operation is likely to be available only in later technology stages of platooning as suggested by SIA Partners (2014[15]) and it is therefore relevant to consider what happens in the transition face. Moreover, even in later stages of platooning, we believe there are challenges with the efficiency of on-the-fly platooning as we will argue in this paper. The idea that platoons can be formed over a longer prediction horizon is also problematic as the transport system is generally an unpredictable environment due to congestion and disruptions. Assuming this will lead to unnecessary waiting time but also in general require a complicated communication setup. In any case it is important to consider other alternatives to the extent these are better.

The contribution of this paper to the existing literature is fourfold. Firstly, we consider platooning from a conceptual and system point of view. We argue that for a system to be successful it needs to be designed such that platoons are formed outside the motorway system, require minimal changes to the infrastructure, and present itself as a positive business case for one or more actors in the industry. Secondly, based on this conceptual understanding of the problem and its solution, we propose the concept of "virtual platooning stations" which do not need any modifications to the local infrastructure at e.g. ports, warehouses or motorway rest stops. For this specific infrastructure, we propose a set of simple strategies for how platoons can be formed. Thirdly, we propose a simple solution algorithm for forming locally optimal platoons at such stations. Finally, we analyse the potential of the proposed strategies on a large-scale real-life case-study at a virtual platooning location close to the Elb-Tunnel near Hamburg.

2. Methods

In the paper we consider a virtual platooning station for which a flow of trucks is observed. Hence, during a fixed time interval (8 hours) a number of trucks will arrive and depart from the station. This could resemble a rest-stop, a warehouse or a port. For simplicity, we assume that trucks arrive uniformly and that the planning of platoons is carried out in fixed time steps during the period. Hence, for each e.g. 30 minutes we solve the truck platoon formation problem and trucks then depart in their respective platoons.

The objective function includes the number of kilometres trucks are driving together. Clearly, three trucks going together will potentially result in more benefits compare to only two trucks. Hence, the objective function is measured as the number of shared kilometres for all "follower trucks". In addition, we also allow the objective function to include additional "platooning costs" at the station, which could include waiting time. In the following we will not consider dedicated time-windows for the participating trucks although this could be introduced in a simple manner. The following policy variables are

N: Number of trucks arriving during the entire time horizon.
M: Maximum number of trucks in each platoon.
t_{tw}: The size of time windows.
t_{max}: End of time horizon (0 is the beginning).
$T = \left\lceil \frac{t_{max}}{t_{tw}} \right\rceil$: Number of time intervals to be optimised.
t_n: The arrival time of truck $n \in N$ sampled uniformly in the interval $[0, t_{max}]$.
$s_{n,m}$: The number of kilometres shared between truck $n, m \in N$.

This gives rise to the sub-problem for each time horizon $h \in 0, \dots, T$, where the set of trucks $N_h \subseteq N | h \cdot t_{tw} < t_n < (h + 1) \cdot t_{tw} \Leftrightarrow t_n \in N_h$ must be assigned to platoons.

There are a maximum of $P = \left\lceil \frac{|N_h|}{M} \right\rceil$ platoons to be formed, and we indicate by $x_{n,p}$, if truck n is assigned to platoon p. This give rise to the following mathematical models (Chow et al. 1964[15]; Lindley, 1961[16]) for each of the T time intervals:

$$Z_h = maximise \sum_{p \in P} \sum_{n \in N_h} \sum_{m \in N_h | m > n} s_{n,m} \cdot y_{n,m,p}$$

St.

$$y_{n,m,p} \leq \frac{1}{2} \cdot (x_{n,p} + x_{m,p}) \quad \forall n, m \in N_h | m > n, p \in P$$

$$M \geq \sum_{p \in P} \sum_{n \in N_h} x_{n,p} \quad \forall p \in P$$

$$1 \geq \sum_{m \in N_h | m > n} y_{n,m,p} \quad \forall n \in N_h, p \in P$$

$$x_{n,p} \in \{0,1\} \quad \forall n \in N_h, p \in P$$

$$y_{n,m,p} \in \{0,1\} \quad \forall n, m \in N_h | m > n, p \in P$$

The first equation ensures that $y_{n,m,p}$ cannot be selected unless $x_{n,p}$ and $x_{m,p}$ both indicate that the trucks are in the platoon. The second equation makes it explicit that a maximum of M trucks can be assigned to each platoon. The third equation ensures that only one $y_{n,m,p}$ can be chosen to indicate that truck n drives behind truck m in the platoon. This will be the one maximising the distance due to the objective function.

The objective function for the whole problem Z is thus:

$$Z = \sum_{h \in 0, \dots, T} Z_h$$

The system is initially solved using a Greedy algorithm. The greedy algorithm assigns the pair of unassigned trucks sharing the longest path to the platoon, and iteratively adds the truck sharing the longest distance with another truck in the pool. Subsequently we apply a local search heuristic that swaps trucks between pools in the same time horizon until no further swaps are profitable. Although this will not in general produce a global optimum it will yield locally optimal solutions that approximate a global optimal solution in a reasonable time.
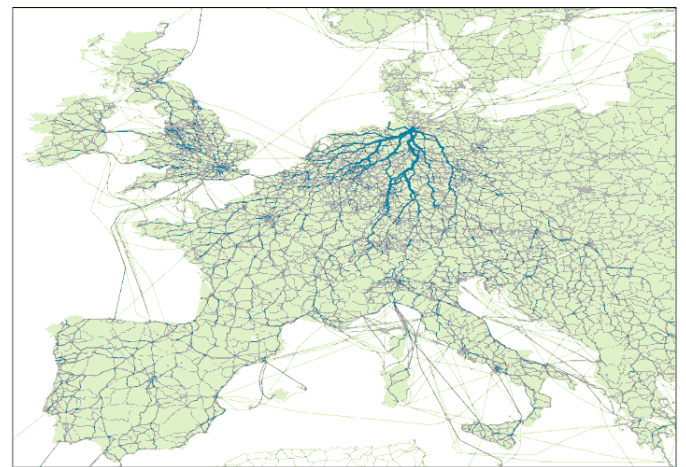

Figure 1: Truck-path pattern for trucks crossing the Elb-Tunnel with destination more than 200 KM away.

3. Case-study

The applicability of the method and its potential impacts is illustrated by use of a real-life case-study. More specifically, we consider the potential of forming platoons for south-bound trucks passing through the Elb-Tunnel on motorway A7 near Hamburg. This is one of the busiest truck corridors in Europe. Data and results have been partly based on the recently developed European wide Trans-Tools 3 transport model (de Jong et.al, 2017[17]; Jensen et al., 2016[18]) for which a new path-based assignment has been used. Each day more than 6000 south-bound trucks pass through the Elb-Tunnel. Of these, approximately 3000 trucks have a destination of more than 200 KM from the Elb-Tunnel (see Fig.1).

4. Results

Below we illustrate results that measure the number of shared kilometres within platoons as a function of platoon size and the size of the time intervals.
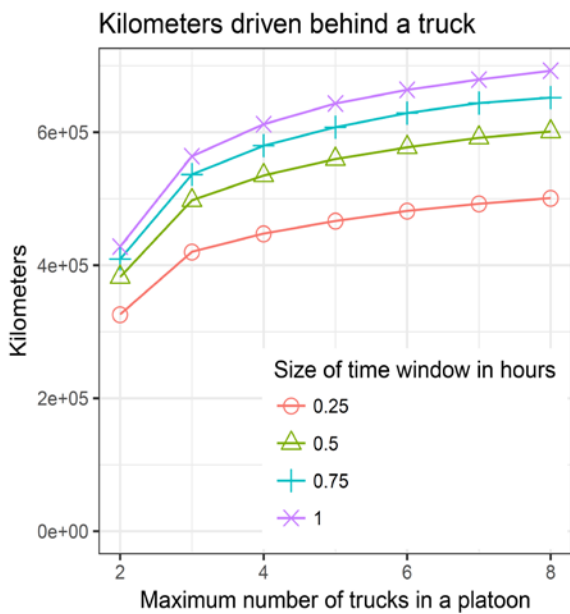

Figure 2: The optimal kilometres of follower trucks in platoons for different allowed platooning sizes and time windows.

Figure 2 clearly show that the joint optimum across all time periods (hence, representing 1,500 trucks) increase by the size of the time windows. This is because wider time-windows give rise to a larger pool of platooning candidates. This on the other hand, proposes that waiting time restrictions or cost should play a role in the optimisation. This, however, is straightforward to do within the solution heuristic.

Figure 3 shows the identical optimum solution but with the window size on the horizontal axis. As commented above, numerous additional constraints can be integrated in the optimisation in order to account for time bindings as well as waiting time. It is also possible to add a platooning-cost and thereby make it possible to simply bypass

platooning options if none exceed the cost threshold for engaging in platoons.
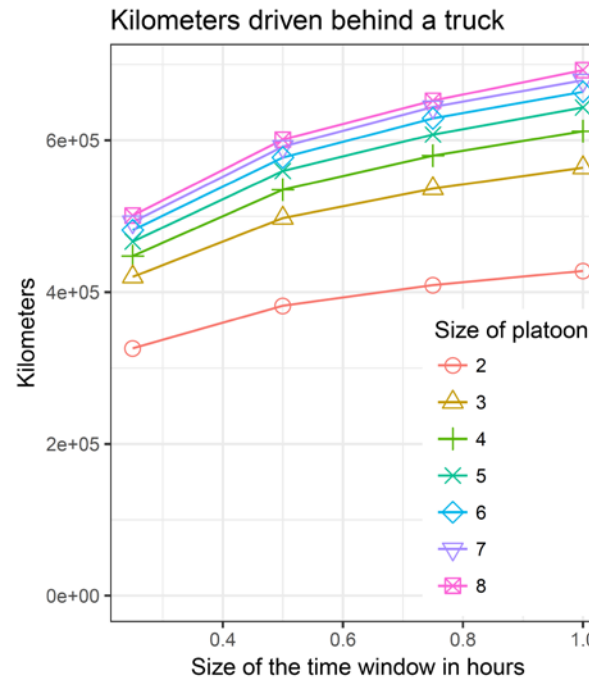

Figure 3: The optimal kilometres of follower trucks in platoons for different time windows and maximum size of platooning.

5. Conclusions

In forthcoming years it is expected that truck platooning will be an integral part of the logistical chain. Platooning can lead to cost savings in the very short run in the form of fuel savings. In a longer perspective, however, it may give rise to a relaxation of rest hour restrictions when it becomes possible for "follower drivers" to rest while driving.

In the paper we propose a platooning system consisting of "platooning stations" located at strategical positions. This could be rest-stops, ports or large warehouses and may require only few changes to the existing infrastructure. Following this, we propose a scalable algorithm for finding optimal platoons at rest-stops for which trucks arrives and depart during a time interval. The algorithm is based on a Greedy heuristic and will provide locally optimal solutions.

In order to assess the platooning potential for a given station we carry out a real-world test by examining optimal solutions for a virtual platooning station located close to the Elb-Tunnel. Optimal solutions for different policy settings are provided, which indicate a substantial potential, although time-restrictions and waiting time need to be factored in.

6. Acknowledgments

7. References

[1]   Geddes, N.B. (1940) Magic motorways. Random House. New Your. Url: https://openlibrary.org/books/OL7205622M/Magic_motorways.

[2]   Stevens, A. (2015). Automated Platooning, Slides for the SATRE project: http://ieeexplore.ieee.org.proxy.findit.dtu.dk/stamp/stamp.jsp?arnumber=7331389

Th. Benz, A. Braun,R. Krause,W. Pöhmller,W.H. Schulz, M. Schulze, J. Sonntag, U. Ulken, Th. Vogel, and D. Vollmer (1996), Telematics Application Programme Sector Transport: PROMOTE-CHAUFFEUR: User, Safety, and Operational Requirements (Technical Report Deliverable D03.1.1 Version 2.0), CORDIS (Community Research and Development Information Service), European Commission, 1996.

[4]   H. Fritz, C. Bonnet, H. Schiemenz, and D. Seeberger (2004), Electronic Tow-Bar based Platoon Control of Heavy Duty Trucks using Vehicle-Vehicle Communication: Practical Results of the CHAUFFEUR2 Project, Proceedings of the 11th World Congress for Intelligent Transport Systems and Services, Nagoya, Japan, October 17-22, 2004.

[5]   https://eutruckplatooning.com/default.aspx

[6]   Bergenheim, C. ; Shladover, S. ; Coelingh, E. (2012) "Overview of platooning systems". Proceedings of the 19th ITS World Congress, Oct 22-26, Vienna, Austria (2012).

[7]   Șerban Sabău, Cristian Oară, Sean Warnick, Ali Jadbabaie (2017). Optimal Distributed Control for Platooning via Sparse Coprime Factorizations. IEEE Transactions on Automatic Control (Volume: 62, Issue: 1, Jan. 2017)

[7]   Nowakowski, C., Thompson, D., Shladover, S.E., Kailas, A., and Lu, X.Y. (2016). Operational concepts for truck cooperative adaptive cruise control (cacc) maneuvers. In Transportation Research Board 95th Annual Meeting, 16-4462.

[8]   Robbert Janssen, Han Zwijnenberg, Iris Blankers, Janiek de Kruijff (2015). TNO Rapport.

https://www.tno.nl/en/about-tno/news/2015/3/truck-platooning-driving-the-future-of-transportation-tno-whitepaper/

[9]   Stevens A., McCarthy, M., Gilhead, P. (2014). Semi-automated heavy vehicle platoons on UK motorways. Report from Transport Research Laboratory.

[10]   Misener J., Zhang, W-B (1015). Technology Road Map, Maturity and Performance: Identification og Technology Issues to Realise Vehicle-Roadway Automation. In Road Vehicle Automation 2. Springer.

[11]   Mallozzi P., Sciancalepore M., Pelliccione P. (2016) Formal Verification of the On-the-Fly Vehicle Platooning Protocol. In: Crnkovic I., Troubitsyna E. (eds) Software Engineering for Resilient Systems. SERENE 2016. Lecture Notes in Computer Science, vol 9823. Springer, Chambridge.

http://link.springer.com/chapter/10.1007/978-3-319-45892-2_5

[12]   A. Bergenhem, Q. Huang, and T. Robinson, "Challenges of platooning on public motorways," in Proc. 17th World Congr. Intell. Transp. Syst., Busan, South Korea, Oct. 2010, pp. 1–12.

[13]   Hall, R. Chin, C. (2004). Vehicle sorting for platoon formation: Impacts on highway entry and throughput. Transportation Research Part C: Emerging Technologies, Volume 13, Issues 5–6, October–December 2005, Pages 405-420

[14]   Sia Partners (2016). Platooning toward sustainable road freight transport. Sia Rapport.

http://transport.sia-partners.com/20160712/platooning-toward-sustainable-road-freight-transport

[15]   Y.S. Chow, S. Moriguti, H. Robbins, and S.M. Samuels. Optimal selection based on relative rank. Israel J. Math., 2:81–90, 1964.

[16]   LINDLEY, D. V. (1961). Dynamic programming and decision theory. Appl. Statist. 10 39-51.

[17]   de Jong, G., Tanner, R., Rich, J., Thorhauge, M., Nielsen, O.A., Bates, J. (2017). Modelling Production-Consumption Flows Of Goods In Europe: The Trade Model Within Transtools3. Journal of Shipping and Trade. DOI 10.1186/s41072-017-0023-9.

[18]   Anders Fjendbo Jensen, Mikkel Thorhauge, Gerard de Jong, Jeppe Rich, Thijs Dekker, Daniel Johnson, Manuel Ojeda Cabral, John Bates, Otto Anker Nielsen (2016). A model for freight transport chain choice in Europe. Accepted for hEART Conference, Delft, 2016.

8. Appendices