Revealing mutual Relationships between Truck Platooning and Smart Hyperconnected Physical Internet Systems

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Abstract: *Sustainability has become a core issue of organizations. In the logistics domain, the vision of the Physical Internet aims to create sustainable logistics networks. Sustainable transport in such networks will still be a core contributor for achieving sustainable operations. This paper investigates contributions of truck platooning, a means for safe and efficient freight transport, to physical internet systems vice versa. The results reveal relationships especially in the PI areas (i) connectivity, (ii) collaboration and coordination as well as (iii) sustainable, safe and secure supply chains.*

Keywords: *Truck platooning, Hyperconnected Systems, Sustainable Transport, C-ITS*

1 Introduction

Sustainability receives increasing attention not only by academics and experts but also by companies and organizations. Within the logistics domain, the vision of the Physical Internet emerged in 2011. The Physical Internet aims to design the way physical objects are moved, handled, stored, realized, supplied and used all over the world in a more sustainable way. The core idea to reach this aim is to build a global logistics network capable of providing real-time information in order to optimize logistic activities. (Montreuil 2012; Montreuil et al. 2011)

However, research and development related to PI is far from being complete. Currently, the European technology platform ALICE[1] (Alliance for Logistics Innovation through Collaboration in Europe) supports the development of a comprehensive strategy for research, innovation and market deployment related to the PI. In this context, the following R&D roadmaps have been developed: (i) IS for interconnected logistics, (ii) sustainable, safe and secure supply chains, (iii) corridors, hubs and synchromodality, (iv) global supply network coordination and collaboration, and (v) urban logistics. Sustainable transport means are an important aspect of PI systems, even if the naming of the given roadmaps does not immediately reveal their importance. Developments in the field of connected and automated driving promise to increase sustainability and as such represent an important enabler for sustainable transport operations in physical internet systems. Vice versa interconnected logistics systems may contribute to optimize automated transport vehicle operations. One development strand in the field of connected and automated driving focuses on truck platooning, which is a promising means to enhance efficiency and safety of freight transport.

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[1] https://www.etp-logistics.eu/

In this paper, the contribution of truck platooning to smart hyperconnected physical internet systems will be investigated. Doing so, related work to truck platooning and initial results from the Austrian platooning flagship project Connecting Austria will be summarized in the subsequent section. Furthermore, mutual relationships between truck platooning and smart hyperconnected physical internet systems will be derived.

2 Related Work

Truck platooning represents a promising means to improve land transport. Via decreasing distances between trucks – thanks to slipstreaming - fuel consumption as well pollutant emissions can be reduced. Typically, distances between trucks are controlled using latest state of the art of automated driving technology. Developments related to truck platooning actually date back to the early 1990s, starting with projects to illustrate the technical feasibility up to projects investigating the potential of fuel savings. In a recent European project – the European Truck Platooning Challenge - original equipment manufacturers even demonstrated platooning across European countries and illustrated that truck platooning could become a day one application of automated driving. The adoption of truck platooning can be structured along the SAE levels for auto-mated driving systems ranging from “Driver Assistance” (level 1) up to “Full Automation” (level 5) (Graeter et al. 2017).

Reviewing recent truck platooning projects and research projects different objects of investigation can be revealed. Energy efficiency related to truck platooning is still a relevant object of investigation. In general, energy efficiency related to freight transport may be increased via means like (i) optimized transport planning, (ii) energy efficient & green vehicles, (iii) energy efficient driving patterns or (iv) intelligent traffic management systems / infrastructures supporting traffic flow optimization. However, the results related to energy efficiency of truck platooning in terms of fuel savings vary across different projects. Simulations related to theoretical potentials of fuel savings result in very promising numbers even up to 10% fuel savings in average within a platoon of three trucks. On the other hand, real life tests reveal lower results, e.g. the EU Companion project observed in average around 5% fuel savings within a platoon of three trucks. Beyond, real life tests in the US (Bevly et al. 2017) revealed that at a speed of 105 km/h fuel savings at a distance of 10 meters were even lower (8.65% for the following vehicle) that at a distance of 15 meters (10.24% for the following vehicle). Furthermore, contextual influence factors like weather conditions, traffic flow, road surfaces or vehicle conditions affect fuel savings. For this reason, actual fuel savings of truck platoon under different circumstances remain an important object of investigation.

Another important object of investigation represents the authorization of truck platooning in different driving situations. Restrictions vary across different truck platooning projects and road authorities, e.g. allowance of platooning in tunnels, at roadwork areas, at “known” critical road sections or motorway intersections are still under debate. Therefore, further investigations related to the ‘permission of truck platooning’ are necessary to inform authorities like road operators or governmental institutions. Evidence-based simulation models and real life test are a suitable means for developing such “permission guidelines”.

Further objects of investigations are for example truck drivers’ issues (Neubauer et al.), interaction with other road users, safety & security, awareness of truck platooning, multi-brand and multi-fleet platooning, or legal aspects. Beyond, the road infrastructure perspective received little attention related to truck platooning so far, e.g. (i) the contribution of intelligent traffic infrastructures towards truck platooning in terms of Infrastructure-to-Vehicle communication and Collaborative Intelligent Transport Systems (C-ITS) or (ii) dynamic infrastructure constraints (traffic situation, weather, road conditions,…).

2.1 Connecting Austria initial results

The Austrian flagship project Connecting Austria[2] brings technology leaders and end-users together to demonstrate and evaluate four specific use cases for semi-automated and energy-efficient truck platoons. Key objective is the evidence-based evaluation of energy-efficient truck platoons as a pre-requisite for the competitive strength of Austrian industries such as logistics, telematics and infrastructure providers, automotive suppliers, as well as vehicle development and cooperative research. The national flagship project's unique contribution is its specific focus on infrastructure issues and on parameterized traffic perspectives when evaluating energy-efficient and semi-autonomous truck platoons. This particularly includes platoons at intersections before entering motorways and after leaving motorways. Key question in Connecting Austria:

- ‘What is needed to safely and efficiently set up an energy-efficient truck platoon, to maintain a platoon, and to go back to a regular transport mode?
- What are pre-requisites and accompanying measures to prepare the future of energy efficient and safe (semi)autonomous truck platoons.’

One preliminary result of Connecting Austria represents the general R&D-Approach. The project studies have been aligned along the potential benefits of automated driving (comfort, safety, vehicle efficiency, traffic efficiency and traffic effectiveness as the overall key performance indicator). In a first run, each of these categories are assessed individually by evaluation of their theoretical limits and potentials. Knowing from (Stadler and Hirz 2014) that practical system effectiveness is normally dramatically less, and from (Kuhn et al.) that all these categories are conflicting each other, in a second run the practical effectiveness ratings of the categories are evaluated as well as the potential risks. The theoretical effectiveness hereby is a good indicator where to spend most development and research effort, for the detailed evaluation (benefit categories with few theoretical potentials will not be exploited into the very last details, research will be concentrated to the categories with the most expected effects). At the end, all the categories with promising potentials will be combined afterwards to a common multi-criteria effectiveness assessment, balancing the individual potential according the desired policies. All effectiveness assessments will be executed for the four selected use cases by intensive scenario management, resulting in the impact layers (infrastructure & V2X & traffic control, vehicle control strategies, laws & guidelines and the dynamic road risk map). Naturalistic driving studies and real traffic observation, delivering representative statistics and reference bases will accompany the assessments.

[2] www.connecting-austria.at

Figure 1: Connecting Austria R&D Approach / Procedures (connecting-austria.at, 2018)

Subsequently, selected results from the first project year of Connecting Austria are presented. Connecting Austria investigates especially level 1 platooning with a special focus on the road infrastructure and innovative C-ITS solutions. The results relate to the following research questions:

- What is the (theoretical/practical) potential for platooning concerning traffic-efficiency?
- What are the advantages of cooperative regulation strategies?
- Which Austrian road sections are ready or candidates for future operation under platooning modes?
- How to evaluate traffic efficiency, traffic safety, environmental impacts and the impact for the logistics industry in Connecting Austria from a systemic point of view?

What is the (theoretical/practical) potential for platooning concerning traffic-efficiency?

One of the expected benefits from automated, connected cooperative driving is an improvement of traffic efficiency and a reduced number of congestions. In technical terms, traffic efficiency means that more vehicles can pass a traffic lane per hour where there is theoretical room for more. Simply deriving from the fundamental diagram ($Q = V \cdot D$, traffic flow is speed times density), this can be achieved by reduction of vehicle distances or by increasing vehicle speeds. Platooning increases the traffic flow rates by reducing distances (increasing density) at constant speed due to reduced following distances. Figure 2 illustrates the theoretical limits for achievable traffic flow rates with given constant speeds for different vehicle distances. Vehicles are assumed to have a length of 4.4 respectively 18.75 m for passenger vehicles and trucks. This graph may illustrate the estimation of the theoretical traffic efficiency potentials. Let’s assume we have a traffic situation, where all involved cars are driving 80 km/h and 2 seconds distance on average. With a ratio of 25% trucks, this would mean, that the traffic flow rate of approx. 1500 vehicles per hour and lane could be increase to approximately 2000 vehicles per hour, if the distance is reduced to 1.5 seconds. These are the best possible values and theoretical limits. The chart can be adopted for different vehicle lengths. Nevertheless, the main issue is that the practical improvement potential may be significantly less. Currently trucks must hold a distance of 50 meters. If trucks in real traffic environments are already driving less distance under certain conditions, the potential benefits due to platooning will be accordingly less. For the investigation of this issue, the driven distances between the vehicles will be assessed in cooperation with the Austrian highway authorities. In this way, we will assess the practical potentials of platooning with respect to traffic efficiency.

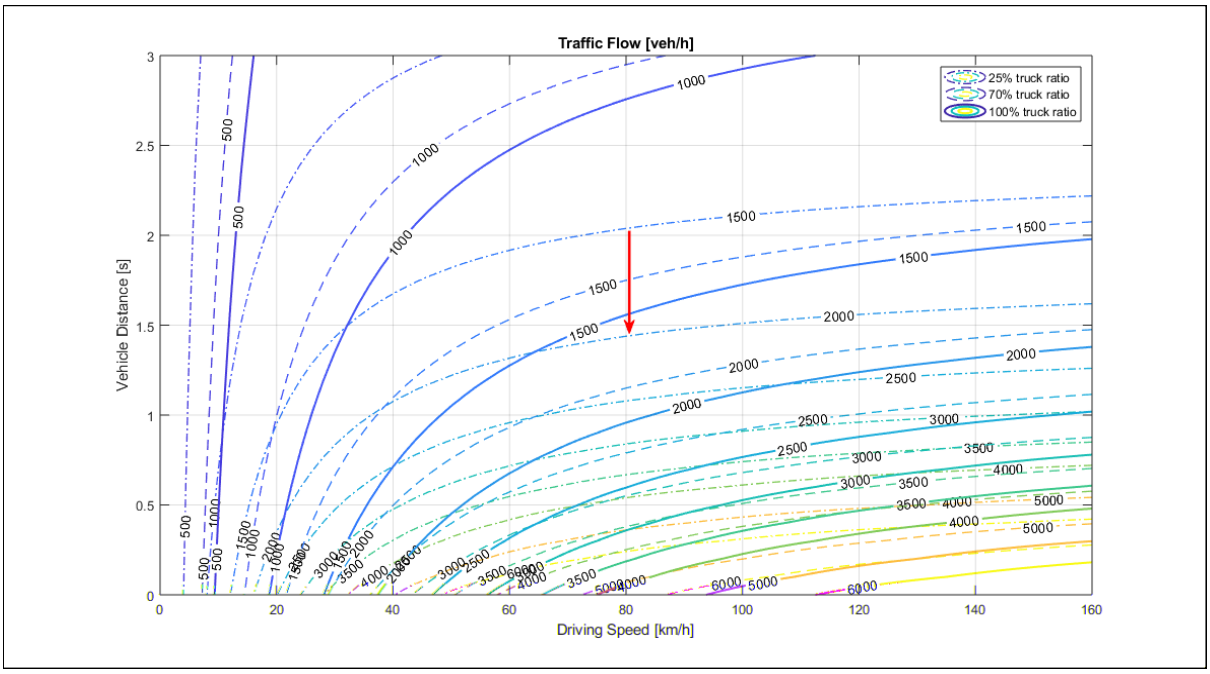

Figure 2: Theoretical traffic-efficiency potential of truck platooning (ANDATA, 2018)

What are the advantages of cooperative regulation strategies?

A unique selling point of the project is that we think of a cooperative system design that manages platoons seen from a road operator’s perspective. More precisely, it is not about managing the processes of finding trucks to platoon for a given time, but to manage the traffic flow including platoons dynamically. For that reason, we identified three crucial technical focus areas: sensor, data exchange and infrastructure based control strategies for use cases in the interurban and urban area (Novak et al.). In the urban area, we are currently focusing on video-based sensors at intersections to receive a picture of the current situation on the road. The idea is to process video data and anonymize it onsite due to privacy reasons. We store the trajectories of pedestrians and cyclists in order to identify if someone is crossing the street. For a first prototype application, we fuse the data of the sensor and the traffic light controller at the intersection to detect if a pedestrian is running a red light. Similar approaches are followed by Honda (Peters 2018), the startup company Derq[3] or Continental (Lauch 2018). Information of such an anomaly is distributed to the platoon via ITS-G5 technology. As

[3] https://en.derq.com/

specified in ECo-AT release 4.0 system specification, we use the ITS service "collective perception" (ECo-AT 2018). In detail, we follow the specification of use case "collective perception of objects on the road". Its scope is to inform vehicles about obstacles on the road, vulnerable road uses as well as critical driving-situations.

Which Austrian road sections are ready or candidates for future operation under platooning modes?

To visualize road sections suitable for platooning a dynamic risk-rated map is generated in an automated way, at the beginning based on geographic information systems and in the future based on additional criteria. Based on specific criteria like

- individual length in advance to of danger zones,
- individual ranges around specific danger point annotated by GPS coordinates,
- special events (e.g. accidents),
- types of street section including individual zones around these (like tunnels, bridges, exits, lane merges, toll stations, etc.),
- topographic properties of the street (e.g. slope, curvature, surface conditions, etc.)

a map will be generated with automated annotation of relevant zone for the allowed vehicle control strategies, like allowed/recommended/forced minimum/maximum distance/speed, etc. The constraints may be adapted with respect to local conditions, traffic conditions, weather, temporal/spatial incidents.

Figure 3: Dynamic risk-rated map prototype (ANDATA, 2018)

How to evaluate traffic efficiency, traffic safety, environmental impacts and the impact for the logistics industry in Connecting Austria from systemic point of view?

As for many emerging CCAM (cooperative connected automated mobility) innovations, it is not entirely clear how they should be assessed without undue anti-innovation bias from outdated methods or lack of large scale validation data. Therefore, in Connecting Austria we have set up a rather large evaluation task force and we have been going the long way of also coming up with innovative assessment and evaluation approaches. Our key baseline is the direct comparison of platooning-type of truck mode to conventional non-platooning type truck mode – all with SAE level 1 and an experienced truck driver with both hands on the steering wheel in each truck. In an effort to avoid too fuzzy concepts and prematurely touching slippery ground we have focused on L1 truck platooning in the specific infrastructure context of Austrian roads and Austrian laws. Key objective of this task force and effort is to come up with validated sound information for decision makers in Austrian road authorities, road operators and transportation stakeholders.

From this objective, each research group in the project has come up with ambitious questions, e.g.:

- What is the platooning potential with regard to truck-efficiency caused by slipstream-effect?
- What is the platooning potential with regard to traffic efficiency caused by increased traffic density?
- What is the platooning potential with regard to energy efficiency caused by predictive power train regulation?
- What are minimum distances of trucks in a platoon without safety risks?
- Which Austrian road sections are ready or candidates for future operation under platooning modes?
- What are advantages of local and temporary densification?
- What are advantages of cooperative regulation strategies at intersections?
- What are validated efficiency gains with platooning?
- Where/when and how would platoons be a safety risk?
- When would ad-hoc platooning make sense with regard to energy-savings?
- What are bottom line platooning benefits for the logistics sector?
- What is the platooning potential for vehicle-safety and traffic-safety?
- What accompanying technical and procedural infrastructure measures are necessary?
- Which organisational and legal changes are necessary in Austria to implement the envisaged advantages?
- How does the behaviour change due to platooning (including other participants)?
- What would be negative logistics impacts from "mandatory" platoons?

Regarding studies related to the logistics impact dimension, results with respect to truck platooning acceptance are presented in (Neubauer et al.). These results indicate that related work in the area of HMI provides insights in how interface designs for platooning should be designed and what are crucial acceptance factors for truck drivers, e.g. related to information provision or situation awareness. Furthermore, existing simulator studies and studies with research and development prototypes in real-world tests provide insights related to the application of platooning. These studies provide for example findings on acceptable distances between trucks, trust between truck drivers or trust in technology as crucial elements for deploying truck platooning.

In general, the results of the empirical acceptance studies conducted in Austria in 2018 confirm the observations presented in the related work. However, there are some differences. For example, within the related work safety and comfort are identified as the main reasons for truck drivers to use automated driving functions. The results of the empirical studies showed that truck drivers do not think that platooning will increase safety. Beyond, the observation indicated that the general intention to use assistance systems may influence the adoption of truck platooning.

2.2 Truck Platooning in Physical Internet Systems

Puskás and Bohács (2019) discuss truck platooning explicitly in the context of physical internet systems. They conclude that platooning systems may contribute to physical internet systems to increase sustainability and that physical internet systems may support interconnectivity e.g. when building ad-hoc platoons between physical internet participants and thereby synchronizing vehicle routes. In their contribution Puskás and Bohács (2019) propose a concept so called “virtual transfer point” for route optimization in physical internet networks.

In addition, Bhoopalam et al. (2018) review platoon planning approaches (scheduled platoon planning, real-time platooning, opportunistic platooning) which may be adopted by physical internet network actors to become platoon members or even platoon providers.

3 Potential Contributions of Truck Platooning to the Physical Internet vice versa

In the previous section related work regarding truck platooning, initial results from the Austrian flagship project Connecting Austria and literature results target towards truck platooning and physical internet systems is presented. In this section, potential contributions of truck platooning to physical internet systems vice versa will be derived.

3.1 Connectivity

Information and Communication Technology (ICT) has become pervasive within the last decades. Thereby, ICT has been a main driver for innovation in the production and the service sector. Recent trends like the Internet of Things, Cyber-Physical Systems, Industry 4.0 or the Physical Internet (PI) represent endeavors to digitize organizational workflows and ensure competitive advantage. These trends aim to further integrate the physical and the digital world to enable communication and collaboration among different organizational actors (people, machines, and even things) and among diverse organizations in real-time (cf. hyper-connectivity, horizontal- and vertical process integration).

With the advent of the Internet of Things the vision of the Physical Internet emerged in the logistics domain. The Physical Internet aims to design the way physical objects are moved, handled, stored, realized, supplied and used all over the world in a more sustainable way. The core idea to reach this aim is to build a global logistics network capable of providing real-time information in order to optimize logistic activities. Thereby, universal interconnectivity among all supply chain stakeholders is considered to be a core enabler. In the context of PI, universal interconnectivity subsumes (1) digital interconnectivity related to connecting diverse, heterogeneous IT-systems, (2) physical interconnectivity in terms of modular load units and interfaces, and (3) operative interconnectivity regarding the alignment of protocols and procedures (Maslarić et al. 2016)

When it comes to platooning connectivity also represents a crucial means. Thereby, connectivity may refer to

(1) technical connectivity, e.g. V2V communication and I2V communication supported by the different technologies (e.g. WLAN ITS G5, 5G), or
(2) organizational/individual connectivity, e.g. multi fleet platooning.

With respect to technical connectivity truck makers' and start-ups' approached truck platooning rather with independent developments than cooperative development efforts. All stakeholders have set-up their own tailor-made truck platooning-prototypes and first demonstrations. This technology-push indicates a quite high technology readiness level. On the other hand, the small number of public tests and already existing truck-platooning vehicles indicates a quite low market readiness level (Hasenauer et al. 2016; Schildorfer et al. 2017) . Peloton[4] – offers commercial level 1 truck platooning services for transport operators and is available in the US. TuSimple[5] - offers all prospects truck platoon journeys; so to experience their platooning solution on public roads. Starksy Robotics[6] – offers truck platooning services in the US since April 2017. Embark[7] – is operating truck platooning since 2017 in the US. Einride – develops the t-pod together with DB Schenker (Edelstein 2018). Plus AI[8] – is operating in China and the US. Uber – stopped its truck programme in 2018. Tesla - Tesla's eTruck 'Semi' does not offer platooning functionality. Volvo[9] – focus on platooning tests in closed areas and research on new business models). Daimler – announced at CES 2019 to stop truck platooning up to level3 (Cannon 2019). MAN – tested with DB Schenker in Germany within the EDDI project[10]). Scania, DAF and IVECO are involved in the ENSEMBLE project[11]; DAF is involved in the UK platooning test[12]. Additional information on truck platooning projects as well as the important role of infrastructure operators in the deployment of truck platooning are mentioned in the Austrian position paper on truck platooning (Hintenaus 2018).

However, a key lesson learnt from the European Truck Platooning Challenge[13] was the need for multi-brand platooning. In other words, the ability to form platoons between different truck OEMs. This key lesson learnt was also confirmed in our stakeholder dialog with fleet operators. They mentioned the necessity of a huge number of trucks equipped with platooning functions and a European harmonised regulatory framework for organizing ad-hoc multi-fleet and multi-brand platooning. Otherwise, they will not invest in any truck platooning technology. This requirement demands for standardized communication protocols. The

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[4] https://peloton-tech.com/
[5] http://www.tusimple.com/index-en.html
[6] https://www.starsky.io
[7] https://embarktrucks.com
[8] https://plus.ai/en/about/
[9] https://www.reuters.com/article/us-volvo-autonomous/volvo-shows-off-selfdriving-electric-truck-with-no-cab-idUSKCN1LS2QP
[10] https://www.bmvi.de/SharedDocs/DE/Artikel/DG/AVF-projekte/eddi.html
[11] https://platooningensemble.eu
[12] https://www.daf.com/en/news-and-media/news-articles/global/2017/q3/30-08-2017-daf-trucks-participates-in-uk-truck-platooning-trial
[13] https://eutruckplatooning.com

H2020 multi brand truck platooning project ENSEMBLE is addressing this issue is ENSEMBLE.

In addition to the technical connectivity, organizational and individual connectivity have been identified as vital ingredient for truck platooning. These results are presented in the subsequent section, which is dedicated to global coordination and collaboration in global physical internets.

3.2 Coordination and Collaboration

In a first step, large fleets might adopt truck platooning. Smaller fleets might need to cooperate with others to find platoon partners and gain benefits from platooning. So far, building a platoon is still an important issue to be resolved. First implementations may use platooning schedules for dedicated routes. On the long run ad-hoc platooning on motorways could be feasible depending on the diffusion rate of platooning capable trucks. However, initial results related to individual aspects indicate that the connectivity between drivers and especially trust will be a crucial ingredient for successfully implementing semi automated truck platooning. With regard to literature on the adoption of truck platooning of fleet operators the analysis of Bevly et al. (2017) showed, "*respondents felt that initially platooning would likely be implemented within-fleet. In terms of platooning with trucks from other fleets, it was noted that trust, assurance, and inter-operability must be clearly established.*"

In order to support platoon building physical internet actors could share planning information and might receive more opportunities for platooning than without collaboration. Aside to collaboration support physical internet actors like platoon providers could support the coordination of platoons. Furthermore, gain sharing between platoon participants needs to be considered. Gain sharing could be realized either by central intermediaries or even via decentralized approaches like blockchain solutions.

3.3 Sustainable, safe & secure supply chains

Truck platooning may reduce fuel consumption and pollutant emission. Nevertheless, with respect to environmental sustainability, the results of diverse truck platooning projects vary regarding fuel savings (cf. related work above). For this reason, actual fuel savings of truck platoons under different circumstances remain an important object of investigation as well as the related emission savings via platooning. These results are relevant for designing transport networks in physical internets. Furthermore, actual fuel savings are directly linked to the economic sustainability for fleet operators. Fleet operators require means to evaluate the impact of truck platooning for their company and to take informed decisions when adopting truck platooning. Furthermore, relevant acceptance criteria such as trust among drivers, reduction of workload, trust in the system, system safety & security are relevant for decision makers. To achieve social sustainability also guidelines for determining situations in which platooning is feasible on certain roads (e.g. depending on weather, traffic situation and road type) are required for decision makers (e.g. road operators, politicians, law).

4 Conclusion

Truck platooning might become a near-term automated and connected driving function. However, truck platooning deployment faces many opportunities and challenges (Engström et al. 2019). Expected benefits from logistics and society tend to be high (Janssen et al. 2015). In order to deploy truck platooning successfully, collaboration among diverse stakeholders will be crucial. Truck platooning system providers will need to ensure technical connectivity as well as system safety & security between diverse truck platooning systems. Fleet operators will need to collaborate to gain fuel and cost savings. Truck drivers will need to collaborate to drive safely in a semi-automated platoon. Truck platooning system developers, road authorities, and governmental institutions will need to develop guidelines for determining situations in which platooning is feasible (e.g. depending on weather, traffic situation and road type).

In this contribution, relationships between truck platooning and physical internet systems have been discussed with respect to (i) connectivity, (ii) collaboration and coordination as well as (iii) sustainable, safe and secure supply chains. Thereby, both may benefit from each other – physical internet systems may support connectivity as well as collaboration and coordination of truck platoon actors; platooning may serve as sustainability means for efficient and safe transports within physical internet networks.

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