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Full platoon control in Truck Platooning: a Meaningful Human Control perspective

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Abstract—Truck platooning is a form of vehicle automation and cooperation that is leading the way for cooperative and automated vehicle implementation. However, much is still unknown about the effects and potential dangers of many situations in regard to cooperative control of these platoons. In this contribution, we discuss many of the challenges in regard to full platoon control, we give concepts that can answer some of the questions and make recommendations on how full platoon control should be considered by truck manufactures, ADS software developers and policy makers. A main concept that is applied is that of Meaningful Human Control (MHC). We furthermore consider driver 'reasons', both distal and proximal, to identify correct chains of MHC. We conclude that each part of a system should be responsive to the maximum amount of relevant reasons available and the availability of relevant reasons should be maximized to obtain sufficient MHC.

Keywords—Truck platooning; Meaningful human control; Vehicle automation; Vehicle control

I. Introduction

Truck platooning has been heralded in recent years as a leading area in which both automated and cooperative vehicle technologies will broadly be applied in practice [1, 2]. The high costs involved in trucking, and therefore potential financial savings, regular and sustained investment, and an already demonstrated proof of concept of truck platooning, makes trucking an area that is attractive to apply the technology. Also, the possibility to start at low levels of automation avoids the necessity to make a big jump in automated control, but allows for a phased application through the levels of automation from *driver assistance*, through to *conditional automated control* and *full automated control*. Current systems are considered to be up to SAE level 2 cooperative systems. This means that a leading truck can independently traverse a road without driver interference for as much as lane changes are not required and complex road sections are not present. Vehicle following and lane keeping is maintained by the vehicles' automated driving system (ADS), which is present in all platooning trucks. Following trucks maintain a close time headway to the leading truck, making use of cooperative technology that allows the leaders' driving parameters to be directly transmitted to the following trucks and allows them to react to speed and acceleration changes from the leading truck with minimal reaction time. The greatest financial gains from truck platooning rely on these short time headways to reduce aerodynamic drag on the trucks and thus reducing the required amount of fuel [2].

However, truck platooning also introduces some technical, psychological, and socio-political challenges. Control over a truck platoon is different from a peloton of non-platooning trucks. The lead truck basically has indirect operational control of the following trucks, in as much as actions by the first truck will directly influence movement by the following trucks in a controlled and predictable manner. This together with the degree of control that a driver has in relation to the trucks' ADS control leads to questions regarding where control actually is applied and to what extent this is desirable or even maintainable for the likes of safety, as well as morally, legally or societally acceptable. Current truck platooning systems require a driver to maintain an active role, even if this is not in operational control (note: this may change in the future) [3]. Part of the reason is that the driver must be able to retake operational control if this if required. This poses questions in regard to safety at the point of the transition of control [4] and also the design of the ADS to allow a driver the time to retake control while still maintaining an acceptable level of overall control. Furthermore, this also connects explicitly to responsibility and accountability, which have been somewhat neglected in control design discussions. When combined with the chain of control throughout an entire platoon, let alone the leading vehicle, this can raise even more questions, regarding the

extent to which the following drivers are able to regain operational control of their trucks given the short headways and the potential lack of explicit information about the leading driver's state of affairs, and who is actually in operational control and responsible at any given time.

In this contribution, we aim to (1) shed light on many of these challenges in regard to full platoon control, (2) introduce concepts that can help address some of the challenges and (3) make recommendations on how full platoon control should be considered by truck manufactures, ADS software developers and the policy makers, such as licencing bodies, that approve vehicles for road use in practice. The main concept that we will introduce and apply is that of Meaningful Human Control (MHC). The concept of MHC entails the extent to which a human can maintain control over an automated system, even when not in (full) operational control (e.g., when an ADS rather than a driver performs operational actions) [5].

The concept of MHC in regard to the traffic domain is described in Section 2. Thereafter, we consider the chain of control within truck platoons, for both the entire platoon as well as individual trucks (and drivers). The concept of MHC is applied to truck platooning in Section 4, including other considerations of maintaining control. Lastly, we touch upon some of the design issues based on this concept, give recommendations towards design implementations, and propose areas for future research.

II. MEANINGFUL HUMAN CONTROL IN TRAFFIC

The term Meaningful Human Control (MHC) originated in the political debate on autonomous weapon systems [6]. This notion has recently been defined by Santoni de Sio and Van den Hoven [5] to depart from an idea of direct operational control of an agent over an action, towards control mechanisms that originate from human reasons to act. This entails the possibility to relinquish (some) operational control, while maintaining overall control, for example by means of system design. It can be naturally applied to vehicle automation, where humans must maintain generic control over a system that is there to aid mobility, but also has the potential to cause undesirable, unsafe or even dangerous situations. Furthermore, it can also help to avoid "accountability gaps", such as situations in which someone is wronged, but where no fairly accountability may be attributed to a human.

The concept of meaningful human control relies on two formal conditions called *tracking* and *tracing*. The tracking condition considers the responsiveness of a system to human reasons to act. In this text, we use the term 'reasons' to denote any factor that can motivate and explain human behavior, such as intentions and plans. In order for a (semi-)automated system [1] to fulfil the tracking condition, its

behaviour should co-vary with the reasons of one or more relevant human agents for carrying out or omitting a certain action X. This condition demands specific design requirements. It entails that an ADS should be designed such that, using all available relevant input, the behaviour of the driving system should be able to follow accepted and agreed upon human decisions to best of its ability. The tracing condition considers the possibility to identify one or more human agents (e.g. ADS designers, drivers, etc.) in the system's design and use history, who are able to: (i) appreciate the capabilities of the system and (ii) understand their own role as targets of potential moral consequences for the system's behaviour. One possible way to ensure that the involved human agents can fulfil the tracking and tracing conditions, is arguably to design the ADS to be maximise accessibility, transparency and explainability of resulting behaviour.

The two conditions for meaningful human control shape a notion of control that is ultimately more demanding as well as more lenient than the classic notion of "direct" operational control, where a physical link is constantly required between human controller and controlled system [7]. It is more demanding, as it prevents certain systems (such as vehicles) to be deemed under human control simply because somebody is 'in-the-loop'. A driver of an automated vehicle, even if they have their hands on the steering wheel, may not entirely be capable of fully understanding their vehicles behaviour. Certain mechanics of the system might be obscure to the driver, excluding them from meaningful control as the tracing condition would not be satisfied. The concept of MHC is also more inclusive than the classic operational control, as it can also include supervisory control, which entails monitoring an intelligent system that is in (full or partial) operational control, and gives the user the ability to undertake action if required. Moreover, MHC is in principle also possible even without direct supervision. A highly automated vehicle may be able to flawlessly track a human's abstract reasons in the absence of any form of direct causal intervention, and yet remain under their meaningful human control.

III. TRUCK PLATOONING CONTROL CHALLENGES

In this section, we discuss the aspect of control over a truck platoon, primarily from a driver's perspective in relation to the cooperative and automated truck systems. This allows us to highlight a number of major control challenges that require due attention. ADS design for truck platooning harbours a number of challenges. In the past, many of these challenges have related to string stability of platoons [8]. Here, we focus more on ADS control from a perspective of human influence, and not on technical design. We presume that the vehicles are capable of automated longitudinal driving. But with vehicle cooperation, control over following vehicles is transferred (in part: merging and exiting still resides with the following driver at all times) to the leading vehicle and its driver. From a behavioural point of view, this

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[1] The notion of intelligent system encompasses numerous possible human and non-human actors, among which the human operators, and all the interfaces that support decision making. The boundaries of the system that one takes into consideration are flexible and should be drawn to include all the relevant components. We are aware that the inclusion criterion of relevance is traditionally problematic [frame problem], but we would ask

the reader to stick with an intuitive notion of it, since an extended discussion would be beyond the scopes of this paper.

throws up a number of challenges for both the leading driver as well as the following drivers.

In traditional truck driving, from a human perspective, driver fatigue is often considered a major factor, although other psychological factors such as attitude and trust should not be underestimated [9]. However, there are two other issues that are especially relevant in regard to a driver's performance in truck platooning. The first is a loss of situation awareness and vigilance, which results from limited vision of the road for drivers in following trucks [10]. The second relates to the platoon lead driver, who now carries responsibility over the entire platoon, and possibly also operational control, which will inadvertently require a high level of trust (in the system and/or themselves) [11]. From a following driver's perspective, it is important to understand the chain of control within a truck platoon. This leads to questions such as: "Who is (ultimately) in control, and where does it leave me?", "If the lead vehicle driver is in control, what influence do I have on my own truck while in the platoon?", and "Would it be of any meaning for me to keep paying attention, since I am not in actual control?". This is just a selection of the questions a driver in a platooning truck could ask. They raise important considerations for the development of truck platooning systems, and especially human-machine interface thereof. This also lies at the heart of ADS design that allows some form of meaningful human control. From the moment a truck driver merges into a platoon, and that driver can take their hands off the steering wheel and their feet off the pedals, operational control over their truck is transferred from them to both the ADS and the lead driver (tactically and strategically). When a following driver aims to exit the platoon, the opposite path of transition occurs. There's a challenge here to have these transitions clear and overt to everyone involved (i.e., traceable), in order to avoid (amongst other things) mode confusion, which entails human cognitive confusion in regard to the status of a system [12], and a potential loss of meaningful human control. The following case gives an illustration of some of the practical challenges:

Consider a truck driver who enters the motorway and approaches a truck platoon. He drives his truck behind the platoon, and sends a request to merge with the platoon. This request is received by the lead driver and accepted, after which both longitudinal and lateral control is taken over by the ADS of the leader's truck, and the truck approaches the now penultimate truck of the platoon up to a time headway of 0.3 seconds [13]. At this point, the (now following) driver can let go of the steering wheel and the pedals and, in theory, not relax, but monitor the system. However, it is unlikely the drivers monitoring will have the required effect, because with such a short time headway between trucks, the view in front is almost completely blocked by the truck ahead, and the means to respond to a given (critical) situation are therefore limited [10].

So what are the relevant elements to achieve meaningful control from the perspective of the following platooning drivers? First of all, the time headway of 0.3 seconds encroaches basic human reaction time, which makes it impossible for following driver to react appropriately to a critical situation, and therefore for the system to appropriately respond to their intentions. Thus, the performance of a sudden hazard evasion movement should arguably not lie with the following driver, but with the leading driver who has a greater opportunity to intervene (e.g., may be steering or at least actively monitoring and ready to retake control). Moreover, a request to intervene has to be processed, and following drivers have to prepare themselves to take over appropriately, which can sometimes take more than 30 seconds [14], and it has been shown that drivers may need up to 20 seconds to retrieve high level situation awareness [15].

More relevant elements for meaningful human control can be identified by considering the perspective of the lead driver. Ideally, they will work with a perfectly functioning ADS, but this will not necessarily always be the case. Their performance now relies heavily on their trust in the ADS of the platoon, and whether or not that is justified. In order for the lead driver to appropriately trust the ADS, and thereby have meaningful human control over the ADS, they will need measured and tailored information about the ADS and its functioning. Thus, to recapitulate, from a driver's perspective, the main challenges to overcome in truck platooning are:

- Role change from active driver to passive monitor,

- Limited time headway and associated front view vision leading to a lack of situation awareness and response time,

- Transition of responsibility to the lead driver, raising issues of trust in the ADS and one's own ability,

- Unclear transition of control, leading to mode confusion,

- Imperfect ADS, also raising trust issues.

IV. MEANINGFUL HUMAN CONTROL IN TRUCK-PLATOONING

We propose that the concept of meaningful human control can aid understanding and address many of the described challenges, as well as some other moral and legal challenges concerning the attribution of responsibility for undesired events in cooperative and automated vehicle systems. In this section, we discuss and demonstrate the necessity to consider control and responsibility from a new perspective for ADS, and that MHC is a very suitable concept for this.

Truck platooning represents an interesting case where multiple human agents – the drivers – are called to participate to different extents at a controlling task. While the leading driver is permanently involved in direct truck operation, the drivers of the following trucks can give up some of their operational control under certain circumstances, e.g. on a highway. This is a classic example of cooperative automated driving, which raises multiples questions in regard to the appropriate distribution of operational control, as seen in the previous section. The leading driver is responsible for operational decision, while the following drivers are asked to supervise the behaviour of their own truck and intervene if required. If we analyse the role of the different drivers of a platoon according to a classic notion of operational control, we see that all the drivers in a platoon, in order for them to remain in control of

their vehicle, are requested to maintain a permanent active focus on their own individual truck's behaviour. Operational control over a system (e.g. a truck) relies on the satisfaction of one main condition, i.e. the presence of some sort of spatiotemporal contiguity, a tight and clear causal connection, between a human agent (the driver) and the acting device (the truck). This approach to control is common and rather consistent with a common intuition of what human control is about.

As we have shown in section 3, satisfying this condition, and achieving operational control, can lead to numerous challenges from a cognitive and behavioural perspective. In this section, we show that adopting a strictly operational notion of control in truck platooning is not only inadequate to account for certain human behavioural characteristics, but it is also inadequate to provide the ground for a fair attribution of moral and legal responsibility within the chain of control, in the event of an undesirable event. Consequently, we argue that the alternative concept of meaningful human control may pave the way for:

(i) a better acknowledgement of the behavioural challenges in automated driving

(ii) a fairer system of attribution of legal and moral responsibility to the individual drivers

(iii) the production of design recommendations to address the behavioural challenges and to realise a fair attribution of responsibility

A. Descriptive case of MHC in practice

Before proceeding, let us recap on what the two conditions of meaningful human control are, and see how they relate to the notion of operational control. The first condition is called *tracking* and requires a system to be reliably responsive to all the reasons of a human agent to act in a certain way, as well as to those reasons to refrain from acting. In other words, an automated system's behaviour should seamlessly co-vary with the reasons of its human controller. The second condition is called *tracing* and, in order to be satisfied, requires that the controlling agent is both (i) capable of fully and thoroughly appreciating the capability of a system, and (ii) able to understand the consequences of its actions, in terms of responsibility and blame. A system that successfully tracks the reasons of a human agent that also satisfies (i) and (ii), can be said to be under meaningful control of that agent.

In order to understand what the implications of adopting the two different notions of control are, we will devise a fictional scenario:

John, the leading driver of a highly automated truck platoon, has been requested to deliver a cargo from Eindhoven to Rotterdam's Europort. However, John has previously had negative experiences with the highway exit that is suggested by the road signs. He knows that he does not want not take that exit, but the following one, but he also decides not to tell anybody, afraid of a loss of face. A few of his following drivers realize that the platoon is not exiting where it should and quickly grab the steering wheel and leave the highway at the correct exit. Other drivers in the platoon remain oblivious and follow John's truck. The detour turns out badly, and the platoon ends up stranded, trying to maneuver in a provincial town. Mr. Bos, the company's CEO, is infuriated, and fires all the drivers that couldn't make it on time to the Europort. "I'm not paying you to sleep", is all he says.

Mr. Bos thinks that all drivers that followed the lead truck are culpable, as they were all sitting behind their vehicle's steering wheel, and thus they were in operational control of their vehicle. After all, simply turning the steering wheel would have sufficed to take the correct exit and, given that all the trucks were working flawlessly in that regard, these drivers were able to steer the vehicle in the correct direction, and hence fully accountable for the troubles they created[2]. As we argued in section 3, Mr. Bos' adopted notion of control does not seem to consider certain limitations that characterize the interaction between a human driver and a (partially) automated system. Also, the consideration that all the following drivers are as responsible as the leading driver might be challenging for certain moral intuitions on a fair distribution of responsibility, namely that a leader could be considered to carry more responsibility than a follower. The concept of meaningful human control, as we will show, can display a better sensitivity to these limitations and can help make sense of the intuitive differences in control and responsibility between the leading and the following drivers.

According to the concept of meaningful human control, each of the drivers should have satisfied different conditions in order to be deemed in control of the whole system, or at least of their individual vehicle. The leading driver is the one that may seem to be fully in control of the platoon's behaviour. The concept of meaningful human control supports this intuition to a certain extent. In terms of tracking, he had clear reasons to steer the platoon away from Rotterdam, and we will assume that the whole system was designed and able to respond accordingly, for as far as other platooning drivers did not take corrective action to remain on course to Rotterdam. The tracking condition seems to be entirely satisfied in this case. Was the leading driver also capable of understanding how the platoon works (first part of the tracing condition)? We will assume he was, to a reasonable extent, given the relative straightforwardness of the system, at least as far as the platoon automation is concerned. The only relevant function of the system that the leading driver needed to understand was that his truck was setting the route for the other ones. Also, in this particular case it seems fair to consider that the drivers are highly trained professionals that should be prepared for such eventualities. Was the leading driver able to understand that he may be considered morally responsible for the effects of his actions on the behaviour of the platoon? We can assume that this is the case as well in this fictional scenario. He explicitly decided not to take the exit while knowing that as a lead driver he would be held responsible for that decision.

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[2] It should be noted that control is only one of the possible requirements for the attribution of responsibility. In our scenario, we will not consider those other factors that may lead to attribute responsibility to the drivers. Ceteris paribus, however, a different degree of control would likely determine a different degree of responsibility

The extent to which the above conditions of tracking and tracing can be, and actually are fulfilled, determines the degree to which meaningful human control can be achieved, and should be carefully assessed from case to case. For our case, we can go on and state that all the conditions were in place for the leading driver to be deemed in meaningful control of the platoon, and, other things being equal, also responsible for its behaviour.

What about the platooning drivers who did recognize the deviation in time and took the correct exit? They all had the intention to travel to Rotterdam, insofar as this was the explicit and unchanged goal of their trip. The system they were acting upon, their own automated truck, responded to their reasons, at least in that occasion. Were they able to fully understand the characteristics and technical capabilities of their own system? Maybe, but they certainly knew enough to understand that if they would steer the truck, the truck would move accordingly. Were they in the position to understand that they would be held responsible for the platoon or at least their individual vehicle not arriving to Rotterdam on time? Probably, which is why they promptly took operational control of their trucks. Does this mean that they were in meaningful control of their individual vehicle? To the extent they succeeded in correctly steering the truck, one would be inclined to answer positively, but here is when things get slightly more complicated. It should be noted that the fact that the truck responded according to their reasons on that occasion does not say much about the actual potential degree of responsiveness to reasons that the system can display. It only says that it responded on this occasion.

In fact, some of the following drivers, although driving comparable trucks, did not succeed in steering their trucks onto the off-ramp on time. Despite having comparable reasons and knowledge of the system to that of any of their fellow drivers, their vehicles did not respond to their reasons to go to Rotterdam. However, this is again not because of any malfunction, but rather it due to an ADS design choice. In fact, their trucks, instead of responding to their own reasons, were responding to the reasons of the leading driver. This is why vehicle cooperation and especially platooning is a relevant case for the discussion on meaningful human control. To understand what this implies for all the drivers in the platoon, in terms of control and responsibility, and to see how ADS design could be improved by this discussion, we need to introduce another conceptual tool.

B. Distal and proximal reasons

A platoon is a complex multi-agent system, with a variety of reasons that can play a role in determining the behaviour of the system. In order to make sense of the important qualitative differences between the platoon leader and the following drivers, it is useful to introduce the distinction between distal and proximal reasons. This distinction, borrowed from philosophy of intention and action [16, 17] allows us to understand certain dynamics of meaningful human control better, and specifically how tracking works. Giulio Mecacci and Sio [18] recently suggested that reasons might be usefully distinguished into 'proximal' and 'distal' with respect to the action they refer to. Proximal reasons are temporally contiguous to the action they are meant to be connected to. Some typical examples of

those reasons can be the *intention* to steer right or left, to hit the brake or accelerate. Distal reasons can be easily understood as *plans*: they are more general and are usually formulated a longer amount of time before the action they refer to takes place. For instance, a typical distal reason in our platooning case might be represented by the intention to go to Rotterdam and timely deliver the cargo.

TABLE I.   SUMMARY OF DISTAL AND PROXIMAL REASONS

Proximal reasons (intentions)	Distal reasons (plans)
Temporally contiguous to an action	Temporally detached from an action
Example: Intention to steer, accelerate, brake…	Example: Plan to skip an exit, to take a certain road, to travel home safely…

Proximal reasons (intentions) typically align to the classical understanding of operational control. They are temporally contiguous to the occurring action. Operational control, in order to be possible, requires the vehicle to remain constantly responsive to those proximal reasons. If the driver fails to switch lane and take the exit, it is because at that very moment they have no intention to steer (perhaps they were distracted). Depending on the extent that the vehicle fully responds to their intentions, they are fully responsible for what the vehicle does. The concept of meaningful human control sets further requirements with respect to the reasons that have to be tracked by the system. According to its original formulation, as stated by [5], the automated system (i.e. trucks) should remain responsive to all the relevant reasons of all the relevant agents in order to fulfil the tracking condition, and its behaviour should seamlessly co-vary with those reasons. An automated system that responds seamlessly to proximal reasons (e.g. to steer or not to steer) might not be able to be (sufficiently) responsive to distal reasons (e.g. to go to Rotterdam and deploy the cargo).

To take our example as a reference, the platoon seems to successfully be tracking the reasons of the leading driver, both proximal and distal. It responds both to the proximal reasons, i.e. the intention to drive forward, and to the distal reason, i.e. the plan to always avoid that certain exit. To the extent that the system also succeeds in fulfilling the tracing condition, we might say that the platoon is under meaningful control of the leading driver, and they might be accountable for their behaviour. When we consider the following drivers, we observe that the platoon -as a whole- seems to be responsive to neither their proximal nor their distal reasons. This is of course a design choice that is inherent to the very idea of platooning, where only the leader sets the route. The system that a driver is meant to be in control of, however, is not the entire platoon, but their own individual vehicle. Each one of those vehicles is designed to maximize its response to their proximal reasons, and react immediately should they need to swerve (half of the drivers pulled that off after all). Where proximal reasons of the following drivers might be successfully tracked by the system, distal reasons might be underrepresented in those drivers' relevant systems, i.e. the single following trucks. Despite the fact that all the drivers had good reasons to get to Rotterdam by taking the correct exit, the system did not respond accordingly. However, this is not merely accidental, but seems to be related to specific

design choices that are inherent to that platooning system. If, and to the extent to which, the system was not designed to comply with those reasons, meaningful human control could not be achieved by those drivers. This would imply that insofar as control is a precondition for responsibility, the drivers might not be deemed fully responsible for the direction their truck took.

What about the drivers who reacted properly and went to Rotterdam? Given that they eventually made it to Rotterdam according to their will, we may be tempted to say that by definition they were in control of their vehicle. However, having observed how the system is designed, and by looking at the behaviour of the other drivers, we might reasonably say that they were not in meaningful control of it either; in a way, they were lucky to be able to steer the vehicle in the right direction in this specific occasion, but they were not in complete control. Should they have failed to express their proximal reasons (that happened to some of their colleagues), the system would have done something regrettable, and plainly against their distal reasons to get to Rotterdam. This is a virtue of MHC, that it allows to make this distinction and offers the tools to analyse such as case, which was not readily or satisfactorily possible before.

Only the leading driver seems to be able to be described as being in meaningful control of his truck and of the platoon in our scenario. Our analysis shows how adopting a different notion of control can lead to different conclusions regarding individual responsibility. It also gives us some design indications to optimize the system for meaningful human control.

V. Design challenges and recommendations

A. Application of Meaningful Human Control

The case we discussed in the previous sections highlights some of the limitations that characterize classical operational of control when applied in cases of cooperative and automated driving. In particular, we have seen how in the case of truck platooning, such a notion is too simplistic to properly deal with certain behavioural challenges, and unsatisfactory while used in establishing accountability for actions. The concept of meaningful human control (MHC) provides the conceptual tools to carve the appropriate distinctions and obtain a clearer picture of the case.

The concept of MHC allows one to make sense of the behavioural challenges; by focussing on reasons, rather than behaviour, it bypasses the excessively strict requirements dictated by the classical operational control. One does not necessarily need to be in operational control to be in meaningful control. The concept also allows responsibility to be attributed and explained, as was shown in the case example. By appealing to different types of reasons to act, the MHC concept provides the conceptual instruments to fully appreciate different shades of control and responsibility. There are still challenges to be addressed in regard to the general conditions of MHC, which relate in part to a further elaboration of the effects of distal and proximal reasons, and in part to how MHC can be applied effectively in practice.

B. MHC considerations for Truck platooning

In our fictional case, the leading driver intentionally concealed their distal reasons, their plan to skip the exit. If the following drivers would have been aware of his plans, they might have prevented their trucks from following the leading truck to the wrong exit, to the extent the system design allowed it. It is not only important that the relevant reasons are maximally available to be used as inputs for the system, but that the system is designed to be as responsive as possible to them. What we learn from this is that a good choice to optimize a platooning system for meaningful human control would be to make every single truck responsive to the reasons of the single driver as much as possible. That system should be sensitive to distal reasons, such as that of reaching a certain destination while driving autonomously, rather than only simple proximal reasons, such as steering wheel operation and following distances. Moreover, one potential design solution could be to have each and every single truck of a platoon under control of the leading driver on the condition that their reasons are compatible with those of the individual following drivers. This would also entail switching from the leading driver's reasons to the following drivers' ones when the condition is not met anymore. This simple proposal has an important and somewhat paradoxical caveat, namely that an increased level of automation can aid achieving meaningful human control. If the following trucks in our case scenario had been responsive to the individual drivers' reasons, they would have automatically exited the highway, immediately -and automatically- dismissing the questionable decision of the leading driver.

From this, we can see that vehicle automation can have the potential to improve on human decision making and potentially generate more meaningful, yes, even more humanly meaningful, behaviour than humans, if the system is designed to properly respond to the relevant distal reasons as well as proximal reasons of the relevant human agents. The discussion so far provides us with one clear design indication: each part of the system should be responsive to the maximum amount of relevant reasons available. Furthermore, the availability of relevant reasons should be maximized.

C. Behavioural consideration for Truck Platooning

There is also much to be said about the responsibility and capability of drivers in truck platoons. Who is in (operational or MH) control and what is required for this? In order for a lead driver to sufficiently trust an ADS, status feedback from the ADS' is required to be able to maintain control over a platoon, to the extent that the lead driver can intervene or alert following drivers in time if something goes wrong. This feedback is twofold: on the vehicles' status and the following drivers' status. A lead driver should be able to trace the ADS' functioning (i.e., be able to follow the chain of control within the ADS), and be updated of the other drivers' state and intentions, as we saw from the MHC reasons. Without information on these two statuses, the lead driver lacks appropriate operational control over the platoon, as should reassign manual control to the following drivers who may not be prepared for this. Furthermore, we suggest providing following drivers with feedback about the current platooning

status, especially prior to a transition to manual driving. Arguably, responsibility over the physical movement of a following truck should not lie with the driver of that truck during the platooning phase, as he would be physically incapable of performing this task in critical situations in case of a control transition request. A following truck driver would require sufficient time to obtain or regain situation awareness before resuming operational control.

VI. Conclusion

Relinquishing operational control to automated driving systems (ADS) poses many questions in regard to safety and moral and legal responsibility. In this paper we have discussed control over cooperative and automated systems with regard to truck platooning. A demonstration is given of some of the control challenges and shortcomings of classical operational control by drivers and ADS. To counteract many of these challenges, we considered the concept of Meaningful Human Control together with explicit reference to the distinction between proximal and distal reasons. The combination of these concepts allows control within a truck platoon to be made explicit and acceptable from various perspectives, such as safety and legal responsibility. We conclude that (cooperative) vehicle automation can have the potential to improve on human decision making and driving behaviour than humans, if the relevant distal reasons as well as proximal reasons of the relevant human agents are properly reflected in the functioning of the system. A clear design recommendation is given that each part of the system should be responsive to the maximum amount of relevant reasons available and the availability of relevant reasons should be maximized. Ongoing work in this direction is aimed at further expanding and addressing control in cooperative and automated vehicles from within the presented concepts.

Acknowledgments

References

[1] Bhoopalam, A. K., Agatz, N., and Zuidwijk, R., "Planning of truck platoons: A literature review and directions for future research," *Transportation Research Part B: Methodological,* 2017.

[2] Calvert, S. C., Schakel, W. J., and van Arem, B., "The influence of truck platooning on traffic flow: considering the main issues and effects," *(submitted for publication),* 2018.

[3] Nowakowski, C., Thompson, D., Shladover, S. E., Kailas, A., and Lu, X.-Y., "Operational Concepts for Truck Maneuvers with Cooperative Adaptive Cruise Control," *Transportation Research Record: Journal of the Transportation Research Board,* pp. 57-64, 2016.

[4] Axelsson, J., "Safety in vehicle platooning: A systematic literature review," *IEEE Transactions on Intelligent Transportation Systems,* vol. 18, pp. 1033-1045, 2017.

[5] Santoni de Sio, F. and Van den Hoven, J., "Meaningful Human Control Over Autonomous Systems, A Philosophical Account," *Frontiers in Robotics and AI,* 2018.

[6] Future of Life Institute. (2015). *Autonomous Weapons: An Open Letter From AI & Robotics Researchers.* Available: https://futureoflife.org/open-letter-autonomous-weapons/

[7] Brookhuis, K. A., De Waard, D., and Janssen, W. H., "Behavioural impacts of advanced driver assistance systems–an overview," *EJTIR,* vol. 1, pp. 245-253, 2001.

[8] Ploeg, J. J., "Analysis and design of controllers for cooperative and automated driving," Technische Universiteit Eindhoven, 2014.

[9] Poulter, D. R., Chapman, P., Bibby, P. A., Clarke, D. D., and Crundall, D., "An application of the theory of planned behaviour to truck driving behaviour and compliance with regulations," *Accident Analysis & Prevention,* vol. 40, pp. 2058-2064, 2008.

[10] Zhang, B., Wilschut, E. S., Willemsen, D. M., Alkim, T., and Martens, M. H., "The Effect of See-Through Truck on Driver Monitoring Patterns and Responses to Critical Events in Truck Platooning," in *International Conference on Applied Human Factors and Ergonomics,* 2017, pp. 842-852.

[11] Hjälmdahl, M., Krupenia, S., and Thorslund, B., "Driver behaviour and driver experience of partial and fully automated truck platooning–a simulator study," *European transport research review,* vol. 9, p. 8, 2017.

[12] Stanton, N. A. and Marsden, P., "From fly-by-wire to drive-by-wire: safety implications of automation in vehicles," *Safety Science,* vol. 24, pp. 35-49, 1996.

[13] Ploeg, J., Shukla, D. P., van de Wouw, N., and Nijmeijer, H., "Controller synthesis for string stability of vehicle platoons," *IEEE Transactions on Intelligent Transportation Systems,* vol. 15, pp. 854-865, 2014.

[14] Eriksson, A. and Stanton, N. A., "Takeover time in highly automated vehicles: noncritical transitions to and from manual control," *Human factors,* vol. 59, pp. 689-705, 2017.

[15] Lu, Z., Coster, X., and de Winter, J., "How much time do drivers need to obtain situation awareness? A laboratory-based study of automated driving," *Applied ergonomics,* vol. 60, pp. 293-304, 2017.

[16] Bratman, M., "Two faces of intention," *The Philosophical Review,* vol. 93, pp. 375-405, 1984.

[17] Mele, A. R., *Springs of action: Understanding intentional behavior*: Oxford University Press on Demand, 1992.

[18] Mecacci G. and De Sio, F. S., "Tracking reasons for meaningful human control," *(in preparation),* 2019.