White Paper:
Automated Driving and Platooning
Issues and Opportunities

ATA Technology and Maintenance Council
Future Truck Program

Automated Driving and Platooning Task Force

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I. Introduction

This white paper examines the intensive activity in the development and introduction of Automated Vehicles (AVs) and identifies potential issues and opportunities. The paper is intended to promote better understanding of this emerging technology and serve as a platform for discussing key areas of interest and concern on the part of commercial fleets. The writing team consisted of the following TMC volunteers:

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This paper was developed by the Automated Driving and Platooning Task Force within the Future Truck Program of the American Truck Association’s Technology and Maintenance Council. The objectives of this task force are:

a. create awareness within TMC of all relevant activities to develop partially automated and fully automated driving systems for heavy trucks, including industry and publicly sponsored R&D, as well as relevant regulatory activity at the state and Federal levels
b. create an operational understanding of how partially and fully automated driving would be applied to heavy truck operations, considering drivers, maintenance, safety managers, fleet managers, regulators
c. define key terms relevant to automated driving so as to create mutual understanding and avoid confusion
d. identify the opportunities, new applications, key requirements, and areas of concern in the evolution of automated driving technologies. Identify technology demonstrations the carriers would like to see.
e. develop a white paper, to include recommended actions that might be taken by industry and regulators
f. liaise as needed to other TMC task forces, such as the S.12 DSRC Task Force
g. develop technical policy guidance for the Technical Advisory Group, ATA Engineering department and ATA Technology and Engineering Policy committee

Commercial Vehicles have particular attributes that make them attractive for early adoption of automated driving technology, including:

a. More compelling business case with respect to fuel economy
b. Ability to leverage an already integrated and sophisticated freight logistics infrastructure
c. Trained and regulated driver base
d. Sophisticated service functions at fleets
e. Short purchasing cycles (relative to passenger car) allow shorter time to critical mass of adoption
Automated control of throttle and brakes is not new to the heavy vehicle industry. Electronic throttle control became commonplace starting in 1990. This eliminated the mechanical linkage to the engine. Radar-based Adaptive Cruise Control systems were first introduced in 2008 and approximately 100,000 trucks operate with ACC today, almost all of them Class 8 vehicles. Building on this type of technology, the focus for this White Paper is on more advanced systems expected to be on the market in the next 1-10 years. Additionally, the focus here is on Class 8 vehicles (Class 3-7 vehicles may be addressed in a future paper). In terms of roadway types, the focus is on typical interstate highways primarily, as well as other road environments (including select off-road environments where trucks operate).

It is important to distinguish the role of automated driving from the crash avoidance systems that are now available for commercial vehicles. Crash avoidance systems assist the driver when “something is wrong” while driving; automation addresses the more general case of normal driving, taking over a task on behalf of the human driver. In practice, both the crash avoidance and the automation levels operate together.

The paper examines both independent automated vehicles (a vehicle operating in automated mode on its own) and cooperative automated vehicles (vehicles connected electronically so as to “platoon” in a close-following mode). The emphasis is on the latter due to significant development activity in this area currently.

The paper is organized as follows:

I. The Basics of Automated Vehicle Technology
II. Status of Automated Vehicles Research and Deployment
III. Automated Vehicle Applications Relevant to Trucking
IV. Driver Considerations
V. Near Term Platooning Operations
VI. Long Term: Independent Automated Operation
VII. Infrastructure and Road Operator Considerations
VIII. Regulatory and Policy Considerations
IX. Recommendations

Several Appendices provide greater depth:

Appendix One: Government Perspectives and Programs
Appendix Two: Industry Association View
Appendix Three: Current Government-Industry Research Projects
Appendix Four: Driver Considerations
Appendix Five: Discussion of Driver Assistive Truck Platooning (DATP) Issues

II. The Basics of Automated Vehicle Technology

II.A. History

Automated vehicles have been dreamed about for at least 70 years and experimented with in fits and starts for roughly 50 years, with major development starting in the 1990’s.

In 1939, General Motors dreamt of a possibility and portrayed it at Futurama Exhibit at New York’s World Fair, envisioning the world in 1960 when a utopian seamless transportation system comprised of intelligent highways and self-driving cars. R&D was conducted during the 1950’s (GM), the 1960’s (Ohio State University), the 1970’s (Tsukuba Mechanical Engineering Lab), and the 1980’s (European Prometheus program). In 1992 USDOT began
the Automated Highway System program, which developed strong technical capabilities and examined societal impacts, culminating with Demo '97 in San Diego. This demo, covered extensively in the media, showcased automated cars, trucks, and buses in a freeway environment – letting the public know that automated driving was more than a dream.

Fast forward to 2004, when the U.S. Defense Advanced Research Projects Agency (DARPA) announced a grand challenge, asking qualified teams to complete a course with their fully autonomous vehicles in the Mojave Desert along a 150-mile route. This was followed in 2007 by the DARPA Urban Challenge, with both cars and large trucks competing in a street environment.

The next era in automated driving opened in 2010 when Google announced they had logged 170,000 miles of driving with its fleet of self-driving cars. Several vehicle manufacturers and major suppliers had been working steadily on similar technology for some time; the Google announcement spurred car manufacturers to accelerate the transition from research to early AV products.

Additionally, different applications of automated driving for trucks have been demonstrated across the globe since the 1990’s. The focus has been on proof of concept for truck platooning due to the foreseen fuel economy and traffic flow benefits. Europeans began their efforts in this area with a project called Chauffeur and it continued with Chauffeur II; this work was followed in the 2000’s by HAVE-IT, SARTRE and Konvoi. During the 2000’s, the Japanese government began a major program to examine truck platooning under the Energy ITS program. Also during this period similar research was sponsored by USDOT and the California Department of Transportation for civilian purposes and within the US Army for military purposes. Overall, this research served to confirm the technical feasibility and in particular the fuel economy benefits of close-headway operations.

II.B. Terminology
In recent years, the industry has sought to settle on common terminology referring to this technology. In early discussions the term “autonomous” was used frequently while some preferred “automated.” Media articles tend to use terms such as “self-driving” and “driverless.” In the end, through involvement of NHTSA and Society of Automotive Engineers (SAE), many of the experts converged and agreed upon “automated” as the most suitable term.

I.B.i. Levels of Automation
In 2014, SAE published standard J3016 which has largely been adopted by the automated vehicle community. The J3016 standard is summarized in the following table.
Key definitions in J3016:

- **Dynamic driving task:** the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task.
- **Driving mode:** a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.).
- **Request to intervene:** notification by the automated driving system to a human driver that s/he should promptly begin or resume performance of the dynamic driving task.

The levels can be simplified by speaking in terms of the driver role relative to today's driving:

- **Level 0:** driver fully in charge (today's driving)
- **Level 1:** driver may be “feet off” if using Adaptive Cruise Control or “hands off” if a Lane Keeping Assist system is engaged
- **Level 2:** allows for both hands-off, feet-off driving – eyes must stay “on” the road
- **Level 3:** enables hands-off, feet-off, and eyes-off. Brain on (driver is able to resume control fairly quickly)
- **Levels 4 and 5:** human driver has no responsibilities

### II.B.ii. Vehicle Platooning

The term “vehicle platooning,” in its broadest sense, uses radar and vehicle-vehicle communications to form and maintain a close-headway formation between at least two in-lane vehicles, controlling the vehicles both longitudinally and laterally at highway speeds, implying at least Level 2 automation.
II.B.iii. Driver Assistive Truck Platooning

Near term versions of platooning only control the longitudinal movement of the vehicle while maintaining a safe gap with the vehicle in front. Drivers in both vehicles remain responsible for steering, implying Level 1 automation. These are referred to generally as Cooperative Adaptive Cruise Control (CACC) and in the trucking industry the term “Driver Assistive Truck Platooning” or DATP has been put forth.

II.C. Enabling Technology

The degree and scope of sensor coverage must be defined for automated driving systems. Sensor coverage needs can vary depending on the level of automation, driving speed, road type, and other environmental factors. For example, high speed driving on a divided highway has one set of requirements, while further coverage may be needed for slower speed operations in the yard where unexpected obstacles such as pedestrians must be accounted for.

II.C.i. On-Board Sensors

Key technological elements for automated driving include on-board sensors (for example radar, stereo/mono camera, and lidar in various combinations). In current prototypes, vision systems are capable of detecting traffic lights (and phase) relevant to the host vehicles’ lane. For Level 2 systems, some passenger car manufacturers emphasize driver state monitoring as necessary to ensure the driver is attentive to the driving scene. Generally speaking, the types of on-board sensors currently found in passenger car safety systems are seen as sufficient for automated driving, with some incremental performance enhancements.

II.C.ii. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communications

During the period in which V2X communications is gradually rolling out in vehicles and infrastructure (several decades), the vehicle industry must rely on on-board sensors for fundamental automated vehicle system operation. Vehicle manufacturers see information flowing through V2V or V2I communications as useful to augment on-board systems; they will use it when it is available. However, deployment of V2V/V2I is not necessary for automated vehicles to be introduced in a general sense.

Truck platooning is an exception, because this application depends on V2V communications between the linked pair of trucks. It does not depend on V2V communications from other nearby vehicles. This is discussed further in later sections.

Mandating V2V radios in all new cars is the focus of a current NHTSA proposed rule-making. If this rule goes through, it is expected to be required in the 2020 timeframe. NHTSA announced some time ago that a decision regarding a similar rule for heavy trucks would be made in 2014. Such a decision has not yet been announced but it is expected to come in 2015. If so, the effective date of any new heavy truck V2V rule would likely be after 2020.

A government mandated V2V communications system will likely include minimum requirements for hardware and messages, communications security, and possibly governance stipulations. Prior to such a mandate, vehicles can use V2V for their own purposes and on their own terms, for applications such as truck platooning. V2V systems implemented for truck platooning may require software upgrades if and when the final rule is announced.
II.C.iii. Digital Maps
For higher levels of automated driving, digital maps will play an important role. As noted above, AV systems will operate via on-board sensing for tactical driving. That said, several OEMs stress the importance of up-to-the-minute map information that can provide information on lane closures, work zones, weather, and other dynamic factors.

Additionally, for localization, there is active discussion of the concept of “digital horizon data” which would primarily be provided via probe data communications from vehicles with relevant sensors (radar, lidar, camera) reporting on an exception basis. This data would provide a reference of what the sensors “see” in the way that they “see” it. From this data, all road and roadside features are detected, including curbs, lampposts, trees, etc. In this way the vehicle can localize itself to the road situation in the same way we do as drivers; the needed level of accuracy cannot be obtained from satellite positioning.

Geographically-referenced vehicle probe data will also be used to make automated driving comfortable for humans. Through probe data, an extensive data set showing how regular drivers drive a particular section of road at a particular time of day, under various road conditions, and in different vehicle types (car/truck). This is considered a good indicator of comfortable human-like driving and can be fed into the vehicle control algorithms. A speed profile for a particular curve in rainy conditions may be one thing if calculated purely based on physics, but incorporating human preferences can be important to engendering trust in the system.

II.C.iv. Cybersecurity
Detecting and protecting against potential cyber-attacks is absolutely essential. However, rather than being an issue specific to automated driving, it is just as much a concern with modern road vehicles in general. Significant advances in vehicle cybersecurity are expected in the coming years based on today’s threats; these advances will benefit AV’s as well.

Currently, vehicles are on the market that are equipped with adaptive cruise control, emergency braking, and lane centering. Strong security measures must be employed to prevent hackers from theoretically controlling these systems from outside the vehicle. Therefore, cybersecurity is a “here and now” issue. Vehicle manufacturers are actively working to define and implement adequate levels of security against attacks, as well as ensuring fail-operational modes when attacks are successful. The design principles being developed now will be applied and refined for automation. The Society of Automotive Engineers is expected to issue a recommended cyber security practice by the end of 2015.

In contrast to the telematics and infotainment systems that have been the main portal for major hacking attacks to date, V2V communications as discussed in this paper have been designed for security from the start. It is essential to maintain communications security for systems relying on V2V, such as truck platooning.

While automation does not fundamentally bring new cybersecurity vulnerabilities, the level of risk for any malicious attack certainly increases at the higher levels of automation in which the driver role is decreased or nonexistent.
III. Status of Automated Vehicles Research and Deployment

III.A. Auto Industry
The automotive industry has been pushing forward with Advanced Driver Assist Systems (ADAS) since the late 1990’s. Examples of such systems are Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA), Collision Mitigation Braking, Speed Sign Recognition, Blind Spot Warning, and Parking Assist. In 2013, OEMs introduced the automated driving systems with capability approaching Level 2. The cost of these combined ACC-LKA systems is in the range of $3000. Technology developments for passenger cars will to some degree translate into heavy trucks. Therefore, a brief summary follows. ¹

III.A.i. Highway-Use Systems
• Co-pilot (near Level 2): a combination of Adaptive Cruise Control with lane centering operating at highway speeds on well-structured highways. These systems became available in 2013. The degree of road curvature handled by the automatic steering differs across car-makers, but in general it is limited to low levels of curvature. This is seen as a means to prevent drivers from over-reliance on the system. They are not intended as “hands-off” systems.
• Traffic Jam Assist (Level 2): a system which provides automated highway driving in traffic jams; it disables above a speed threshold in the range of 30 mph. Even though the system is capable of automatic steering, the driver is expected to keep their hands on the wheel; some systems automatically detect this and alert the driver if their hands are off the wheel for too long (on the order of 15 seconds), disabling the feature if the driver does not respond. These systems became available in 2013.
• Highway Pilot (Level 2): a capability (hands-off, feet-off) for highway use across the full speed range. Since this is an eyes-on system, some approaches will actively monitor the driver’s attention/gaze and warn if the driver does not have eyes on the road. Some systems will simply drive the vehicle in-lane; others will also perform lane changes as needed. These systems are expected to incorporate Traffic Jam Assist as well. Passenger car OEMs have announced availability of this system in the 2016-2018 timeframe.

III.A.ii. Automation on the Streets
The complex and varied situations encountered in street driving places this capability much later in the timeline; however many automakers are working actively to master this environment as well. Level 2 product introductions may come by 2020, operating in well-structured and well-marked street environments.

III.A.iii. Automated Valet Parking
Level 4 automated valet parking for passenger cars is an interesting application which will come near term because it is low speed and operates off the public road. The idea is that the driver steps out of the car at the entrance to a parking facility and uses their smartphone to instruct the car to park. The vehicle autonomously drives away empty and finds a space, returning to the entrance when called by the driver. These systems are expected to be available in the 2016 timeframe.

III.A.iv. Automated Taxi Services (Level 5)
Automakers are beginning to discuss the convergence of car-sharing and AV as potential future products. This is a natural convergence, as some automakers have launched car-sharing services. Such “robo-taxi” services would bring a car where it is needed to pick up a passenger, and when the passenger has disembarked it would drive away on its own to pick up someone else. The vehicle would park itself automatically as needed, as well.

The major player in this space however is Google. Rather than the incremental approach of the vehicle industry, they seek to transform mobility, in particular serving the needs of those who cannot drive now (blind persons, the elderly). Google is now testing automated vehicles on California and Texas surface streets in preparation for offering robo-taxi services in the coming years. Such deployments will be important symbolically but limited in impact, as these systems will operate in confined geographic spaces and the number of vehicles will be small, at least for the foreseeable future. Some car-makers are pursuing similar services, and Uber – a crowd-sourced transportation company - recently established a research center focused on driverless Uber ride services.

III.A.v. On Road Testing
Vehicle manufacturers evaluate their prototype systems through typical means such as simulation and track testing. However, assessing the performance of AV systems requires significant on-road exposure as well, to encounter and understand the vehicle’s response to unpredictable “real world” situations. As an in-between step, local governments and universities are setting up specialized test facilities which offer realistic environments within a large closed course consisting of many miles of several types of roadway. Examples are the Mobility Transformation Center at the University of Michigan and ICAR at Clemson University.

III.B. Commercial Trucking Industry
The commercial vehicle space is not far behind the car side. In fact, some experts contend that automated trucks will arrive sooner than automated passenger vehicles due to offering strong business propositions such as improving fuel economy, reduced frequency and severity of accidents, and more.

Suppliers and OEMs are working to introduce or have introduced many of the building blocks required for the automated truck. Advanced automatic transmissions, electronic stability control, and electronic power steering are just a few examples of such developments that enable truck automation. Adaptive Cruise Control, a Level 1 system, has been available on Class 8 trucks for many years, and automatic emergency braking (also Level 1) is mandated on new trucks in Europe as of 2015. Truck OEMs and suppliers are now developing and testing the first generation of trucks with automation capabilities. There is also a start-up company that is preparing to introduce the truck platooning application in two-truck pairs with longitudinal control only (DATP).

The International Road Transport Union (IRU), representing commercial trucking in Europe, issued a draft policy document in 2013 addressing automated driving; this is included as Appendix Two.

The two primary approaches under system development are introduced here, with more detail provided later in the document.
III.B.a. Truck Platooning (Level 1)
Building upon radar-based Adaptive Cruise Control systems and adding V2V communications, two or more trucks can "electronically couple" such that any braking by the lead truck can instantaneously be initiated by following trucks. This enables inter-vehicle spacing to be greatly reduced, which improves aerodynamics and reduces fuel use.

Initial systems are expected to be Level 1, only controlling brakes/throttle with the driver steering (since automated steering does not improve fuel economy). Truck-makers and suppliers are actively developing these systems; implementation is expected within a few years. Steering may be added for driver comfort in a later generation.

The key issues for deployment of platooning relate first to demonstrating that this type of close following is safe; in addition, some state-level regulatory agencies must be engaged due to language in their Driving Code (which was developed for human driving) requiring specific minimum following distances of hundreds of feet.

III.B.b. Highly Automated Trucks (Levels 2 and 3)
Testing of Level 2 automation for Class 8 trucks is underway in the U.S., offering a combination of ACC and Lane Keeping.

In May 2015, Freightliner announced that it had been granted licenses for road testing of trucks equipped with their Highway Pilot automated driving system (Level 3) in Nevada. Their prototype truck automatically complies with posted speed limits. They do not perform automated passing or merging/maneuvers; these must be done by the driver. The driver can deactivate the Highway Pilot manually and is able to override the system at any time. If the vehicle is no longer able to handle the driving, the driver is prompted to retake control with enough time for the driver to gracefully re-engage driving. To provide an indicator to other road users, the license plate, indicators and the radiator grille shine blue when the vehicle is in automated mode, and white and yellow in standard operation.

This full Level 3 AV capability for trucks will most likely come in the next decade (several truck OEMs have shown prototypes and one indicated the 2025 timeframe). At some point the role of the driver in actually driving will be diminished to the point that they can handle other administrative logistical matters while the vehicle is taking care of the driving. This opens up the possibility for changes in Hours of Service regulations; however any serious consideration of changes is not expected in the next ten years.

III.C. Government Perspectives

III.C.i. USA Federal Government
NHTSA issued a Policy Document on Automated Driving to help states implement AV technology safely so that its full benefits can be realized. The document defined five levels of automation, described envisioned research, and discussed technical challenges such as human factors, reliability, cybersecurity, development of system performance requirements, and defining test and evaluation methods. While recognizing many unanswered questions

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regarding AV operation, NHTSA affirmed the potential benefits of AVs.

Given the relatively early stage of development, NHTSA recommended states not permit operation of "self driving" vehicles for purposes other than testing, which appears to refer to Levels 3 and higher; this does not appear to apply to early versions of truck platooning as described above (DATP), as these would be Level 1 systems.

In 2014, USDOT's Intelligent Transportation Systems Joint Program Office published an ITS Strategic Plan for 2015-2019. The plan has two strategic priorities: Realizing Connected Vehicle Implementation and Advancing Automation. Under these are five strategic themes and six program categories; these are described further in Appendix One.

USDOT initiated several projects in AV starting in 2013. These are described in Appendix Three.

The Department of Energy is launching a program called Systems and Modeling for Accelerated Research in Transportation (SMART), which will focus on energy and mobility. DOE's National Renewable Energy Laboratory has conducted testing of truck platooning systems to evaluate improvements in fuel economy; results are provided in Section VI below.

III.C.ii. State Governments
Several state governments have taken specific steps to allow for testing of AV's on public roads, and legislation to do so is pending in other states.

The most detailed regulations allowing testing of AV's on public roads were developed and issued by the California Department of Motor Vehicles in 2013 (as of late 2014, 29 licenses had been granted). Among a variety of stipulations, the regulations require certificates of self-insurance plus requirements to report any instance in which the automation failed. A set of regulations for operational use of AV's by the public is expected to be issued in 2015. This may include a requirement for a driver's license endorsement to operate AV's.

Other states allowing testing of automated vehicles are Florida, Michigan, Nevada, as well as the District of Columbia.

Some state level regulations also address minimum following distances, which can affect the deployment of truck platooning. This is addressed further in Section IX Regulatory and Policy Considerations.

III.C.iii. Europe
The European Commission has funded significant work in automation and several projects are ongoing (see Appendix One). The Horizon 2020 Transport Workplan 2014-15 aims to "support gradual progress towards full automation" via development of new technology, human machine interfaces, and new transport and mobility concepts.

Individual European countries also fund research in the AV domain. More information is provided in Appendix One.

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A key regulatory issue relates to the Vienna Convention, to which European countries are signatories. The Road Traffic section of this document, written before AV’s were envisioned, presents some roadblocks to AV operation on EU roads. (The U.S. is not a signatory to the Convention.) Further, UN Economic Commission for Europe (ECE) defines additional factors which may limit AV’s. The industry is working with government to potentially amend these documents to enable AV operation. It is likely but not certain that the needed amendments will be ratified to clear the way for AV operation; the timing is not clear.

III.C.iv. Japan
Japan has been active in AV R&D since the 90’s but until recently had their strongest focus on V2X. However, during the 2000’s, the Japanese government conducted a major program to examine automated truck platooning under the Energy ITS program. On a test track, four trucks were platooned at an inter-vehicle gap of under 4m. With a three truck platoon operating at a 10m gap, fuel economy testing showed a 4% improvement for the lead truck, 19% for the second truck, and 17% for the third truck, for a platoon average of 13% fuel use reduction.

Public road testing of AV’s by car manufacturers has been underway in Japan since 2013. Currently AV research and deployment is one of a small number of high profile national strategic initiatives. The work includes both passenger cars and trucks.

IV. AV Applications Relevant to Trucking
The following are representative applications of automated driving in trucking operations; this list is not intended to encompass all possible applications.

This section is subdivided into Independent Operation and Cooperative Operation. Independent AV systems use on-board systems to provide the information critical to driving (they may also be receiving GPS signals plus connected to the cloud for other functions). Cooperative AV systems use on-board systems plus vehicle-to-vehicle communications to provide the information critical to driving, i.e. vehicles are “coupled” for more efficient operation.

IV.A. Independent Operation
The following applications are listed in order of increasing automation levels. In terms of highway use, higher levels are farther out on the timeline. However, in closed environments, very high levels of automation are already in operation.

IV.A.i. Traffic Jam Assist (Level 2)
Description: As in the passenger car systems described above, Traffic Jam Assist for trucks would operate the same way, as a system which provides automated highway driving in traffic jams; it disables above a set speed threshold which would indicate that the traffic jam is dissipating. Depending on the level of automation, the driver may or may not be expected to keep hands on the wheel.

Possible timing: 2017-2019

IV.A.ii. Automated Trailer Backing (Level 2)
Description: Backing a trailer into a loading dock requires substantial skill. Given the driver shortage, a system which can automatically maneuver the tractor-trailer...
combination at low speeds in a precise manner to optimally place the trailer could support drivers with less experience.

Possible timing: 2018 - 2020

**IV.A.iii. Highway Pilot (Level 2 and above)**

Description: This is envisioned initially as a Level 2 capability (hands-off, feet-off, eyes-on) for highway use across the full speed range; in later years Level 3 systems (hands-off, feet-off, eyes-off) are expected to emerge. Eyes-on system approaches may actively monitor the driver’s attention/gaze and warn if the driver does not have eyes on the road. Some systems would simply drive the vehicle in-lane; others would also do lane changes as needed.

Possible timing:
- 2018-2020 (Level 2)
- 2020-2023 (Level 3)

**IV.A.iv. Automated Movement in Queue (Level 3)**

Description: At ports and other areas where trucks are forced to queue to enter the facility, typical movements are start-stop similar to a traffic jam. However, all vehicles are trucks and the movement may be taking place off the public road. This creates a more benign deployment environment. Such a system could completely free the driver from tedious driving by automatically moving the vehicle within the queue.

Possible timing: 2018 - 2020

**IV.A.v. Automated Off-Highway Material Hauling (Level 4)**

Deployment of fully automated trucks in off-road environments is an important early step towards bringing AV technology to the highways. The open pit mining industry has deployed driverless heavy haulers for several years, mainly overseas. Recently Suncor, Canada's largest oil company, announced they will purchase driverless trucks to work the Alberta oil fields.5

Timing: now

**IV.B. Cooperative Operation**

Cooperative systems exchange information critical to vehicle control is via wireless communications, as noted above. The majority of application development focuses on "platooning," i.e. relying on vehicle-to-vehicle communications such as Dedicated Short Range Communications (DSRC) (cellular communications may also be part of the system's communications suite). As the U.S. gears up for a possible mandated deployment of DSRC on new vehicle sales, the advent of platooning on commercial trucks will be a significant factor in early deployment of DSRC for safety and other applications.

Additionally, other emerging radio technologies could be utilized for V2V communications to enable cooperative driving systems, such as hybrid systems using Frequency Hopping Spread Spectrum. There is interest in using LTE-A/LTE-Direct as another means to enhance V2V communications.

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5 “400-Ton Driverless Trucks Headed to Alberta Oil Fields,” Transport Topics, June 19, 2015.
communications. Such DSRC alternatives would need to exhibit the same or better characteristics with regards to resiliency and security of communications.

Interoperability between trucks is fundamental. However, initiating DATP operations does not need to wait on government action. Prior to any government regulations to require DSRC on heavy trucks, platooning can be done with data protocols specified by vendors and/or fleets.

IV.B.i. **Driver Assistive Truck Platooning (Level 1)**
Description: DATP systems are designed for highway use. They provide longitudinal control only; the driver is responsible for steering. Braking and other relevant information is sent from the front truck to the rear truck to enable close following. As a nearer-term system, DATP would focus on two-truck platoons initially. DATP is aimed at taking advantage of increasing maturity of V2V communications, plus widespread deployment of V2V connectivity expected over the next decade, to improve freight efficiency, fleet efficiency, safety, and highway mobility, plus reduce emissions.

Possible timing:
- 2016 (fleet pilots)
- 2016 - 2018 (deployment)

IV.B.ii. **Driver Assistive movement in Queue (Level 1)**
Description: This is a low-speed application, similar to DATP, in which the system provides longitudinal control only; the driver is responsible for steering. Braking and other relevant information is sent from the front truck to the rear truck to enable close following, relieving the driver of the tedium of movement within a slow-moving queue.

Possible timing: 2018-2020

IV.B.iii. **Highly Automated Platooning (Level 2 and above)**
Description: Full platooning systems provide both lateral and longitudinal control at highway speeds. Braking and other relevant information is sent from the front truck to the rear truck(s) to enable close following. Fully automated platoons could consist of several vehicles.

Possible timing: 2020-2022 (Level 2)
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V. Driver Considerations
System developers must account for the impact of various driver issues when designing the capabilities and logic of automated driving systems. These driver issues will have influence on the effectiveness of the complete system. More broadly, key issues with the implementation of the automation in heavy trucks will include trust, driver acceptance, training needs, and generational issues.

V.A. Early Forms of Automation
Drivers must keep in mind that they are the prime control system no matter what the vehicle is capable of doing. It must be clear what degree of situational awareness the autonomous commercial vehicle has so that the driver has a clear understanding of what situations they must handle.

Drivers that slip seat between vehicles will have to be aware of the features of the specific vehicle they are driving, since two trucks of the same make and model may be equipped differently.

V.B. Higher Levels of Automation
In Level 3 Conditional Automation, the driver must be available to assume control if requested by the AV system. After potentially long periods of system control, will the driver be capable of re-assuming vehicle control in a reasonable amount of time when environmental conditions change and the automated system is no longer capable of providing the required level of control? This control transition is currently being studied and methods of ensuring a safe transfer are being investigated. For implementation of Level 3 automation, this transition issue must be successfully resolved. While the reliability of a passenger car driver in such a role might be questionable, this role is more plausible with a well trained and regulated driving population as is found in commercial vehicles.

Figure 1: Estimated Introduction Dates of Truck-Related AV Systems
Reliable means of determining driver state, and its role in successful implementation of automated vehicle technology, is a key issue for the industry. When the AV system ratchets from one level of automation to another, or disengages completely, it could become essential to ensure the driver is aware and ready for this change, either via actively measuring the driver’s state or some process of dialogue with the driver.

Depending on the level of automation, it may be permissible to take eyes off the road to handle other matters, which today would be defined as “driver distraction.” But the meaning of this term will evolve as AV’s come into use. Given the monotony of simply monitoring the driving of the AV system, secondary tasks may actually be helpful for the driver in staying alert.6

Research findings published by Daimler Trucks7 indicate that automated driving systems ease the workload for truck drivers. They studied the influence of automated driving systems on the attentiveness of 16 truck drivers on a test track with their Highway Pilot system and two different conventional trucks for four hours without a break. EEG and ECG measurements were taken during the four-hour drive,8 which made it possible to determine the level of fatigue of the test subjects. Of the participating drivers, 12 had no previous experience with an automated truck. However, after the drives they stated that they had grown accustomed to the Highway Pilot quickly and confirmed that this system made driving considerably easier. Daimler Trucks concluded that a driver is more attentive and consequently able to perform better if the use of the Highway Pilot system allows him to also do other jobs instead of having to perform monotonous driving-related tasks. The brainwave measurements indicated that drowsiness was reduced by 25% when the truck operated in autonomous mode and the test subject performed interesting secondary tasks (e.g. on a tablet computer). Subjectively, the drivers reported they were more alert and more attentive while driving in automated mode.

Driver considerations are discussed in greater detail in Appendix Four.

VI. Near Term Platooning Operations

This section addresses the Driver Assistive Truck Platooning (DATP) type of Level 1 automation. This type of system appears to be closest to market introduction relative to other types of systems described above.

As described above, in the DATP application trucks are exchanging data, with one or more trucks closely following the leader in automated mode (the driver remains responsible for steering). V2V communications ensure that the degree of any braking initiated on the lead truck (prior to brake engagement and vehicle deceleration actually occurring due to brake system time lags) causes braking on the follower truck to be commanded at the same or

6 “Piloted Driving Safety and Side Tasks.” Dr. –Ing Björn Giesler, Audi AG. Presented at we.conect TechAD, February 2015.
8 Electroencephalography (EEG) is an examination method from neurology that provides a general picture of current brain activity, including the level of attention. An electrocardiogram (ECG) records the electrical activity of the heart and provides information about the driver’s current physical stress.
greater deceleration level, virtually simultaneously. This is the key to enabling following distances shorter than a human driver can manage safely.

This process is illustrated conceptually in Figure 2, in which the horizontal axis is time. The top example depicts the braking process in which the following driver is performing the braking with no assistance. When the front truck brakes are applied, actual braking occurs after some lag. The following driver takes time to perceive and react to this to apply the rear truck brakes, which also occurs after some lag. The middle example shows the lags in an automated system without V2V. The sensor in the rear truck only becomes aware of front truck braking after braking actually occurs, some time after the front driver has initiated braking. Perception and reaction time to automatically brake is required here as well, but it is very quick compared to a human driver. Thus, safe following distances can be reduced compared to a human driver. The advantage of V2V-based platooning is shown in the bottom third of the chart. Because brake application on the front truck is communicated instantly to the rear truck, very little time elapses between brake initiation on the front and rear trucks. This enables the much smaller inter-vehicle gaps which provide fuel economy gains due to drafting.

DATP platooning systems should not decrease the overall level of safety to road users. Ideally, due to the collision avoidance technologies underpinning the system, DATP will provide a net safety improvement.

It is important that the inter-vehicle gap setting take into account several factors to set a safe gap. Key factors are:

- Engine horsepower
- Estimated mass of each vehicle
- Estimated braking ability of each vehicle (measured in real time). Factors affecting braking performance include:
  - Estimated mass of each vehicle

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Source: Peloton Technology

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**Figure 2: Brake Application Timing w/ Coordinated V2V**

**Cut-In’s and Cut-Off’s**

Today, truckers experience other vehicles on the highway cutting them off, requiring immediate braking by the driver (or automatic braking systems).

In platooning, these “cut-offs” from other vehicles ahead of the lead truck can still occur. Plus, passenger car drivers may “cut-in” between two platooning trucks. The system must adapt to both situations to maintain safety.
- Weather conditions
- Brake condition
- Road conditions
- Ability to cool engine with adequate air flow
- Driver acceptance
- Traffic conditions
- Road configuration (including tight curvature and/or dense entry/exit sections)

Based on these factors, the system should define and implement a safe distance, including a safety margin. The safety margin must take into account uncertainty as to real-time braking ability. Typical distances are expected to be in the range of 40-50 feet; however in some cases the conditions may warrant setting a platooning distance greater than what an average driver would use.

There will be conditions in which platooning is not advisable. Platooning system developers should consider how to adapt platooning protocols under these conditions.

A set of performance parameters have to be met to ensure trucks are compatible for platooning, i.e. to “match up” two vehicles. System developers must work with carriers to clearly define parameters that determine this proper match in equipment.

Public acceptance must also be considered. Impacts on surrounding traffic seeking to merge on or off the highway could be a factor; however platoons of only two trucks are unlikely to be considered a problem in free-flowing traffic.

VI.A. Industry Context and Business Case
Under the FHWA sponsored truck platooning project led by Auburn University\textsuperscript{10}, a business case analysis for DATP was performed by ATRI which addressed the users, sectors, and business models that are most likely to adopt DATP systems. ATRI conducted an industry survey that solicited both carrier and driver cost and benefit expectations. Due to limited industry knowledge of platooning at this time, the survey should be viewed as an initial investigation that may be refined as stakeholders gain better understanding through demonstrations and pilot tests. Nevertheless, insights can be found from these early results. Findings from the survey include:

- The DATP concept is most advantageous when travel speeds are higher, truck trips are longer (i.e., benefits accrue over time/distance), and the likelihood of encountering similar trucks installed with DATP technology is high.
- Industry data derived from surveys and technical reports (e.g. ATA Trucking Trends 2013) indicate that over-the-road operations, with an emphasis on “truckload” (TL) and line-haul “less-than-truckload” (LTL) sectors would experience the highest likelihood of encountering the desired DATP attributes. In particular, truckload operations often have pre-determined routes or corridors between large freight generators (e.g. business parks, manufacturing centers, warehouses, retail establishments).
- Truck routing: based on survey responses, 75% of the time the truck routing was determined in advance of the trip. Although the survey data shows that a meaningful


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number of these trips experienced unexpected route changes, the ability to potentially concentrate DATP-installed trucks through advance planning may increase industry interest, at least by those TL firms that have multiple DATP trucks and dedicated routes between freight generators.

- The largest percentage of TL trip mileage occurs on highways and interstates, which immediately improves the attractiveness of DATP to this sector. Based on the survey, 71% of the TL mileage was generated on limited access interstates and highways.

VI.B. Potential Benefits

Long haul trucking alone represents more than 10% of US oil use, with fuel representing 38% of fleet operating expenses. Trucks are only 4% of the vehicles on the road but consume 20% of transportation fuel. To illustrate this, in 2013, trucking consumed more oil than the U.S. imported from the Persian Gulf. Testing in past research for automated platooning has shown significant fuel economy benefits due to close-headway following enabled by the V2V communications link. A 2013 test of an early DATP implementation showed significant fuel economy improvements on the order of 4.5% for the lead truck and 10% for the following truck, when traveling at (100 kph) 64 mph at (11m) 33 ft spacing.\(^\text{11}\)

In 2014, DOE’s National Renewable Energy Laboratory (NREL) conducted tests of platooning systems implemented by Peloton Technology.\(^\text{12}\) The SAE J1321 Type II Fuel Consumption Test Procedure was managed by NREL, using vehicles loaded at 65,000 lbs running at up to 70 mph. 20-75 foot inter-vehicle gaps were evaluated. The testing documented up to 5.3% fuel savings for the lead truck and up to 9.7% fuel savings for the trailing truck.

The Dutch research group TNO published an extensive study on two-truck platooning in early 2015.\(^\text{13}\) The authors note that the political and economic climate there is positive for a broad deployment of platooning; initial legislation changes have already been proposed to allow testing and experimentation on Dutch roads. To maximize benefits, they introduce the concept of a Platooning Service Provider (PSP) to support ad hoc formation of platoons. The PSP would help platoon partners find one another on the road, as well as certify participants: “For on-the-fly platooning it is not necessary to know exactly where your platoon partner is going. However, for reasons of safety and trusting your platooning partner – especially if you are the driver of the Following Vehicle – you might want to know where your platoon partner is going, whether the leading driver took the required rests, and whether the Leading Vehicle is in good mechanical condition and is properly maintained. PSPs can establish quality schemes such that truck drivers can have the confidence that on-the-fly platoons are only formed with ‘trusted partners’. The PSPs also deal with administrative duties from the platooning activities, arrange insurances, and make sure that benefits of platooning are distributed fairly among the platooning partners.”

They note that platooning will allow a more optimal use of the available road capacity. In a typical scenario, they calculate that two trucks platooning at a .3 second gap (9m at 60 mph)

\(^\text{12}\) Transportation as a System: Getting SMARTer on Energy and Mobility. Presented by Rueben Sarkar, Assistant Secretary - Transportation, DOE at the 2015 Automated Vehicles Symposium, July 2015.
\(^\text{13}\) “Truck Platooning: Driving the Future of Transportation.” TNO, February 2015. Available at: http://repository.tudelft.nl/search/tno/?q=title%3A%22Truck%20platooning%20%3A%20Driving%20%the%20future%20of%20transportation%22
would decrease the length of those two trucks by 46%, from 82 to 44 m. Thus, the amount of road space taken by the two trucks is essentially halved.

Using rough estimates for system cost and costs of service providers, maintenance, and driver training, they performed a case study based on typical operations of two specific over-the-road fleets operating in the region. The fuel savings were much greater than the costs; both Fleet A and Fleet B saved approximately $14,000 per truck per year. They also calculated savings for a “one driver” platoon, in which a driver is not needed in the follower truck (a much longer term proposition.) The results in terms of fuel cost reductions are compelling: $36,000 per truck per year for Fleet A and $21,000 per truck per year for Fleet B.

The TNO report estimated the timeline for two-driver and one-driver platooning as shown in the chart below. (The authors of this White Paper expect two-driver platooning to come sooner than these estimates.)

![Figure 3: TNO Timeline for Truck Platooning](image)

The TNO team provided a useful summary of overall benefits via this chart.

![Figure 4: TNO Summary of High Level Truck Platooning Benefits](image)
Extensive additional analytical work and testing should be performed to further explore fuel economy and other benefits. For instance, what is the exact relationship between following distance and fuel savings? At some close following distances engine cooling could become an issue, requiring additional use of the engine cooling fan and therefore extra fuel; this relationship in particular needs to be understood.

VI.C. Considerations for Fleet Operations

VI.C.i. Platoon With Whom?
Intense competition in the trucking industry makes the question of whom to platoon with one of the most challenging aspects of DATP. Based on the ATRI industry survey, across all respondent groups, 68% to 71% of trips are on the same routes which allows for more advance planning of potential DATP interactions. In general, all respondent groups favored platooning within their own company or, in the case of owner-operators, with other O-Os. Doing so generally minimizes conflicts associated with helping a competitor improve their bottom line.

It appears that knowledge and trust improves the likelihood that DATP usage would increase over time, as many respondents favored platooning with fleets/trucks with whom they had previously platooned.

An approach which initially only links to trucks of the same fleet may be a starting point; however, protocols enabling any pair of equipped trucks provide for the greatest benefit and usage levels.

VI.C.ii. Equipment Factors
Priorities and observations resulting from industry outreach within the Auburn project and further discussions in preparation of this White Paper are as follows.

a. DATP systems should be interoperable among trucks of different brands and with different options.

b. DATP-equipped trucks should feature forward collision mitigation and avoidance systems such as systems available from vendors today. DATP applies these systems to enable cooperative braking between the two trucks, although other cooperative braking solutions could be developed outside of the collision mitigation and avoidance systems available today.

c. Vehicle brakes must be in compliance with FMVSS standards and FMCSA compliance requirements.

d. The DATP system must accommodate differing braking capabilities between the paired vehicles. The relative braking ability of each truck should be estimated and taken into account for vehicle control, for example, so that the front and rear trucks in platoon can be arranged according to their relative braking capabilities.

e. The mass of the tractor-trailer combinations and their impact on platooning operation must be known or estimated. This is a factor in calculating relative braking capabilities.

f. Vehicles may need to be matched (in terms of horsepower and grade ability) depending on the specific DATP system design. This may include data entry for specifications such as gear ratio.

g. The performance parameters which must be met to ensure trucks are compatible for platooning must be defined. One method of doing this may be to specify a minimum horsepower and minimum speed capability on a 2 or 3% grade. With the minimum capability being set, the information provided by V2V communication enables the lead vehicle to not outperform the second vehicle in acceleration.

h. Older equipment incapable of platooning may have to be relocated to areas that do not use platooning, or the fleets may want to consider short trade cycles.

i. DATP-capable vehicles may be assigned to locations that have routes that will work best with platooning.

j. DATP systems should account for the braking capabilities of each individual truck, including how these abilities change according to road conditions.

k. Road spray for the trailing truck could be an issue; this should be investigated as a factor in setting an appropriate following distance in wet weather.

VI.C.iii. Dispatch Factors

DATP systems which come to market must address a variety of factors for optimizing dispatching with respect to platooning. Additional priorities and observations resulting from industry outreach within the Auburn project addressed this issue. Some key considerations for system designers are:

a. Even in operations in which a large portion of shipping lanes or partial lanes have multiple vehicles moving, matching closeouts and dispatch times could be a challenge. Fleets are typically intentional in pushing for early closeouts and spreading these dispatches. Holding dispatches for platooning could impact crewing, transit time, and dock and yard congestion; these effects would need to be played against the benefits of DATP operation. However, some fleets indicate that they already have groups of trucks out together on dedicated shipping lanes such that they can arrange two-truck platooning without significant changes to dispatch timing.

b. Some fleets have very sophisticated line haul systems matching loads, equipment, drivers, schedules, etc. which involves already complex models to which platooning will add further detail, particularly to the extent that platooning is occurring with other carriers' vehicles. Therefore, current fleet dispatching and freight handling software may need to be upgraded to accommodate DATP operations. Fleets must retain discretion over how their models may change to account for platooning.

c. Many of the longer dispatches with the biggest opportunity for the benefits of platooning now contain mid-points. These have been useful to balance line haul, manage hours of service, and to get drivers home. The mid-points – where drivers meet, switch trailers and turn – should be recognized in planning for platooning runs.

d. Matching within-fleet vehicles for platooning needs to be done in a way compatible with workload balancing at both the sending and receiving locations.

e. Dispatch time may need to take into account the effects of heavy traffic periods so that traffic will not be a problem for platooning vehicles or cars that are on the road with platooning trucks.

f. Is scheduling drivers any different from non-platooned trips? The prerequisite for scheduling drivers is primarily a function of his/her being qualified and trained for platoon driving.

g. Dispatching drivers with available driving hours to match the dispatched vehicle could present challenges, particularly if it is necessary to hold drivers until a second vehicle is ready to leave.
h. The ideal DATP system will not require load matching. If it is necessary to match loading, not being able to load a vehicle to the maximum so that other vehicles going in the same direction can be loaded with a near equal load could cause a need for more dock doors and dock workers for a short period of time. Scheduling workload hours and dock door pressure are key factors for P&D cross docking operations. Just-in-time delivery makes it necessary to move freight quickly with no delays.

i. For carriers that have just-in-time and guaranteed deliveries, releasing a load early to match another lighter vehicle could mean that more trucks will have to be dispatched. This would drive the cost of operations up.

VI.C.iv. Operating Speed
For DATP operations between trucks from different fleets, how should operating speed be defined when linked? Today, each fleet defines its own operating speed. They also have limits set under various operating conditions that are unique to their operation. Top speed can be different with cruise and without cruise. Horsepower and powertrain configurations determine low speed operation while pulling grades. If these practices are left at the fleet level then inter-fleet platooning must take them into account.

VI.C.v. Coordination for Linking
Approaches to DATP pairing must be further clarified. Fleets may have to establish the rules of engagement, and/or inter-fleet platooning could be arranged on the fly using either V2V or cellular communications (such as the Platooning Service Provider concept noted in the TNO Study). The process has to be done in such a manner that the route, logistics, and safety are not compromised.

Auburn researchers performed a detailed analysis of the potential likelihood of pairing opportunities under the FHWA sponsored truck platooning project. The case study analyzed truck fleet data (provided by ATRI) to determine the impacts of platoon formation on several key metrics, including the number of platoons that may be formed from historical truck routes, the maximum size of any platoon formed, and the total time lost as a result of trucks slowing down to form a platoon.

The analysis assumed that all of the trucks in the datasets were platoon eligible. New optimization algorithms were developed that determined which trucks should join to form a platoon, given the starting location of each truck. A core research question addressed the relative likelihood that trucks will be able to find platooning partners, given typical distributions of within-fleet trucks on highways. This analysis found that formation of two-truck platoons among platoon-eligible trucks was between 3%-45% depending on the fleet. Further, trucks forming two-truck platoons in these datasets traveled within a platoon between 30-75% of the distance of the 300-mile road segment, on average. More information on this analysis can be found in Appendix Five. Further analysis of these factors are ongoing within Phase 2 of the FHWA-sponsored Auburn project.

VI.D. Safety and Operational Requirements
Cut-offs and cut-ins by passenger vehicles are unfortunately a too common scenario in highway operations. DATP often builds on radar-based Adaptive Cruise Control (ACC), which

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has been in use by the trucking industry for almost a decade, as well as more recent collision mitigation systems (CMS) which aggressively brake in a situation in which the truck may strike the rear of an encroaching vehicle. Thus, ACC/CMS systems assist the truck driver in braking as quickly as possible to a cut-in vehicle with a speed differential that may cause a forward collision.

With DATP, when a passenger vehicle cuts-in between two platooning trucks, the rear truck must respond and brake appropriately to attain a safe following distance behind the encroaching vehicle. This process must operate even if V2V between the two platooning trucks is blocked, i.e. using radar sensing only.

Due to the laws of physics, not all collisions can be avoided but these systems can at least reduce the energy in a crash that is unavoidable. A "safe" DATP system should therefore be viewed as one which responds to a developing crash situation as quickly as possible (and significantly faster than a human driver could) to either avoid the crash or slow the vehicle speed to reduce the energy in a crash.

Relative to the use of today's Adaptive Cruise Control, the potential for a near-crash or crash due to passenger vehicle cut-offs or cut-ins does not change with platooning; however the potential of cut-ins may be somewhat reduced due to the closer spacing between trucks. At the same time, a passenger car that does choose to cut-in between two platooning trucks creates a safety critical situation. Analyses should be conducted to estimate the likelihood of such events for various platooning following distances. Initial results from an ongoing USDOT study indicate that cut-in's by passenger vehicles are uncommon with inter-vehicle distances of 100 feet or less.16

Successful implementations of DATP within fleets may provide a compelling business case for further penetration of currently available safety systems such as ACC/CMS, as well as other safety systems.

Further inputs provided by industry stakeholders to the FHWA-sponsored Auburn project are provided in the next sections.

VI.D.i. General Operations
   a. The DATP system should operate on limited access highways such as interstate highways and major US highways, and operate across typical cruising speeds.
   b. The DATP system should operate across a defined set of weather conditions; operations shall be adjusted based on weather conditions as needed to maintain safety. System developers need to clearly specify limitations relating to weather.
   c. The DATP system should control engine torque, gear selection (for automated manual transmission vehicles), and braking including engine brakes/retarders as well as foundation brakes.
   d. The DATP system should allow the driver to control throttle, braking, gear selection, and steering at any time.

VI.D.ii. Designing for Safety
   a. Based on estimated braking ability, the vehicle with the better braking ability shall be designated as the rear vehicle for maximum safety.

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16 Report is expected to be published in late 2015.
b. The DATP system shall adapt to variances in braking capability between the two trucks and variation on each truck, in terms of defining the ordering of vehicles (leading, following) and in setting inter-vehicle spacing. The degree of uncertainty in estimating braking ability of both trucks must be included in the inter-vehicle spacing determination.

c. System developers should implement the system such that varying levels of brake performance (within acceptable bounds) are not an impediment to use of the platooning system.

d. The DATP system shall use data from both vehicles to continually calculate optimum inter-vehicle distance to maintain a safe stopping distance in an emergency braking situation.

e. The DATP system shall adjust operating parameters to respond to weather conditions that could affect braking distance. This could include maintaining platooning and separating the trucks up to a distance typical of manual driving.

f. The J1939 bus of the truck will contain any faults from the stock ECUs of the truck. These include items such as emissions issues which can impose limits on torque production or otherwise impact the operation of the platooning system. These will be read directly from the J1939 bus, and conform to the standard. The system shall respond to faults in a manner to ensure safety.

g. Redundancy: Redundancy in its simplest form is an overlap between functional safety and business case. Functional safety demands redundancy, and the greater the amount of redundancy, the more sophisticated failure management is possible. With no redundancy, loss of a sensor or processor could compromise system performance. System developers need to address the degree of redundancy required to fulfill safety and performance requirements.

h. Communications: Integrity of communications must be maintained to the maximum extent; the system must effectively handle degradation / loss of communications.

i. In the case of loss of satellite positioning data, the DATP system shall use the sensing subsystem to maintain spacing in relation to the lead vehicle, sufficient to safely separate the two vehicles while this condition persists.

j. In the event of faults or failures, the system should be designed in a “fail operational” manner to ensure driver and vehicle safety.

k. Functional Safety: Functional safety is both as a process and a state of development. The European passenger car industry has developed ISO 26262 that provides for a determination of the appropriate functional safety status and the process to achieve it; they are devoting significant resources to implementing ISO 26262. Although ISO26262 was developed for light vehicles, it is broadly relevant to addressing functional safety for truck technology. The European commercial vehicle industry and the North American passenger car industry are in the process of applying ISO 26262, and this can be expected for the North American commercial vehicle industry as well. Given the passenger car adoption of ISO 26262, parallel adoption by the commercial vehicles industry could be constructive in designing DATP and more advanced forms of automation.

VI.E. Maintenance Considerations
It is vital to ensure that today’s technicians are able to trouble shoot problems with the electronics and sensors needed for this type of operation; systems should be designed with this in mind. Ideally, maintenance protocols and diagnostic tools already used for advanced technology systems (such as ACC and lane detection) can be used with only minor adaptations. Techniques for maintaining DSRC-based V2V communications need to be developed.
Various forms of automatic vehicle health monitoring are being offered by manufacturers which may be helpful in maintaining DATP systems. In particular, brake condition monitoring is important.

The degree to which technicians need to be trained and/or certified to maintain DATP systems needs to be defined.

The time interval for inspection and re-certification of systems needs to be clearly specified.

When lateral control is also provided in platooning systems, existing test procedures could be useful. Lane departure warning test procedures are developed in SAE J3045. Although the test procedure does not presume particular technology, cameras are a common means of detecting lateral lane information. Camera information can be augmented by GPS information combined with maps. This information can be used to as an input to electronically controllable steering systems.

**VI.F. Driver Considerations for Platooning**
Accommodating truck drivers' needs and expectations will be one of the most important requirements of a successful DATP system. With the growing economy and baby boomer retirements, the truck driver shortage crisis will become more critical. ATRI conducts an annual survey of industry stakeholders and the “truck driver shortage” issue rose to number two in the 2014 survey.

Within the FHWA-sponsored DATP project, ATRI addressed several driver topics. Clearly, ensuring truck driver support and satisfaction with DATP usage is essential. There is a large range of issues and concerns raised in the ATRI industry survey relating to truck driver usage and truck driver retention. Fifteen percent of fleet managers indicated that the DATP systems would have a “very positive” or “somewhat positive” impact on driver retention, while 39% believe it will have no impact. Additionally, 39% of fleet respondents think that drivers are very likely, likely, or moderately likely to use the system. Owner-operator responses for driver retention or usage were not positive, but their generally lower preference for DATP may be due to lower profit margins and less available capital.

Future conclusions from the project based on stakeholder feedback follow.

**VI.F.i. Operating the System**
Driver expectations: The driver interface with the platooning system must be designed to match the driver's expectation and mental model of how the system should couple and decouple the vehicles.

Because the platoon is a gathering of linked vehicles, there must be established rules for how drivers are to commingle in the platoon. The establishment of such rules and compliance should be considered.

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Because of close proximity of the vehicles during platooning, the system must account for the latency of the driver reaction times in the software logic in addressing situations in which driver action is needed to maintain safe operation.

**VI.F.ii. Driver Interface for Platooning**
Technology developers must create intuitive driver interfaces that allow driver to cooperate with nearby vehicles to establish a platoon. These key interfaces include:

- a. Following-vehicle request to join
- b. Lead-vehicle accept to join
- c. Headway adjustment
- d. Disassociate from platoon
-   a. Notification of disassociation
-   b. Request for disassociation
-   c. Acceptable frequency
- e. Other Vehicle intrusion (cut-ins)
-   a. Notification to platoon
-   b. Resolution

Any system-induced changes to operational mode (such as delinking or fault handling) shall be indicated appropriately and be understandable to the driver; the driver’s responsibilities in these cases (if any) shall be clearly indicated.

The delinking operation should be smooth and predictable to the driver, providing sufficient time for the driver to retake full control of the vehicle. For example, within the de-linking process, the vehicle could maintain longitudinal control until the driver re-engages the throttle and/or brake. A smooth and predictable de-linking operation shall apply whether the driver or the system initiates the delinking process.

**VI.F.iii. Training Needs**
As automated technology is implemented in heavy trucks, developers need to ensure that drivers are educated on the functions of the system, protocols for lead drivers and following drivers, and procedures for irregularities in the system performance.

In particular, asking drivers to operate at inter-vehicle distances that are foreign to their normal operation (and training) must be approached with appropriate understanding and new training protocols.

Drivers must also be trained to be fully aware of the capabilities of the vehicle they are driving and the mode of automation which is active (and the system itself should clearly indicate the current mode of operation). Drivers operating automated trucks in platooning mode and non-automated trucks will become used to following the vehicle ahead very closely. When not in automated platooning mode, drivers must be trained to back off from the preceding vehicle when there is no electronic assistance in operation.

As a new field, only limited work has been done to develop training programs for future driving with platooning technology. This is an area that needs further attention.

**VI.F.iv. Driver Experience**
The relationship between following distance and driver comfort/stress should be investigated.
Additionally, driver vigilance could suffer if the experience is too monotonous. Studies would be useful to assess driver’s capability of controlling a vehicle with minimal following distances for long periods of time while experiencing the lack of a large field of view, especially behind a van trailer. Such studies should assess the issues and also investigate means of countering any negative effects.

As DATP evolves, the pros and cons of adding lateral control to fully automate the vehicle to address any driver issues should be examined.

**VI.F.v. Driver Responsibilities**

While linked, the rear driver’s task is very similar to that with adaptive cruise control. Braking and acceleration shall be fully automated and the rear driver is responsible for lateral control of the vehicle at all times.

The driver should take over full control at any time he or she is not confident the system is operating properly.

If the front vehicle changes lanes, the rear driver shall do so as well whenever it can be safely achieved, if continued linking is desired.

**VI.G. Standardization and Interoperability**

In terms of safety of AV system design, the car industry has taken the lead in developing “functional safety process standards” for advanced vehicle control systems. ISO 26262, software structure standard Autosar, as well as the various CAN communication standards such as J1939 all serve to allow sub-system integration. ISO 26262 and Autosar are more readily adopted in the passenger car domain. In some respects, J1939 may not be sufficiently robust for real time control of safety critical systems. This should be further examined.

In terms of standards specifically related to truck platooning, there is activity within the Society of Automotive Engineers to amend SAE J2735, which defines message sets for V2V communications, with an additional section defining V2V messages for truck platooning.

As noted above, NHTSA is developing a proposed Federal Motor Vehicle Safety Standard (FMVSS) to require V2V communications capability on all new light vehicles. They are likely to make a similar determination regarding heavy vehicles; in this case, NHTSA has the authority to require the technology on both new and existing heavy vehicles. In the absence of a regulation, fleets can implement DATP now for within-fleet operations. If in the future an FMVSS goes into effect requiring V2V on existing heavy trucks, fleets with existing V2V operations may need to upgrade software (and possibly hardware) to comply.

Priorities for communications and data interchange in a DATP system identified in stakeholder discussions follow.

a. The DATP system shall provide critical vehicle operational parameters between paired vehicles. The minimum parameters are:
   a. Braking status: deceleration, torque, and pressure
   b. Engine torque
   c. Acceleration/Deceleration in the longitudinal direction
   d. Location, vehicle velocity, and direction
   e. System status (truck and DATP system)
   f. Vehicle Size
b. This data shall be coded into messages consistent with applicable standards.
c. The inter-vehicle communications system shall continuously monitor the communication quality and reliability and provide this information to the system controller, such that a loss of communication is detected within 50ms.
d. The inter-vehicle communications system shall include one or more 5.9 GHz DSRC antennas installed so as to preserve line of sight between the vehicles when a trailer is attached.
e. The radios shall handle antenna diversity as well as standard protocols to optimize robustness of communications.
f. Bandwidth of the communications channel shall be adequate to support continuous video streaming as well as data exchange.
g. The inter-vehicle communications system shall implement information security measures to prevent intentional disruption of or tampering with the communications link.

VII. Long Term: Independent Automated Operation
The prospect of vehicles able to safely drive automatically in an automated mode, such that the driver does not need to be constantly attentive, represents a game-changer in trucking.

In the foreseeable future, the driver will still be required in the vehicle. The driver is an important part of the system and must remain able to control the truck in certain traffic situations on the highway and on country roads, as well as in city traffic and when hooking up a trailer or making deliveries. In all cases, automated driving systems should have fail-operational and/or fail-safe features in the event the driver is incapacitated.

Nevertheless, enabling drivers to gain time for other tasks will dramatically change the job of a truck driver, potentially creating career opportunities for drivers to become “transport managers.” Ideally, the trucker job will become more attractive, easing the existing driver shortage.

In terms of operations, commercial vehicle dynamic properties can vary significantly with load. As automation evolves into higher levels, the automated vehicle may have to not only recognize variations in its own vehicle dynamics, but also communicate relevant vehicle dynamic properties to other vehicles to cooperatively eliminate/mitigate accidents.

VIII. Infrastructure and Road Operator Considerations
Current AV systems under development do not rely on any particular infrastructure installed specifically for automation. This aspect should be examined for advanced forms of AV.

With respect to connectivity, commercial vehicles communicate with the infrastructure through cellular or satellite fleet communication systems and weigh in motion systems. Before automation, these features were adopted based on specific business case considerations. Infrastructure-based communications (I2V / V2I) may come and be helpful to automated systems, but data from these communications might not be a necessity.

Traffic impacts should be well understood. Ideally, these impacts (for mainline flow as well as entry/exit) should be examined across various levels of market penetration, across light and heavy truck traffic corridors, and across platoon length (two, three, or more trucks).
when platooning. Once traffic impacts are understood, road operators should examine different rules on different corridors, if this fulfills policy goals for traffic and freight efficiency. For instance, roads serving ports might allow longer platoons than the overall road network.

Current introductions and plans for AVs from industry envision operation in mixed traffic in regular lanes. The value (and practical feasibility) of dedicated truck lanes (or AV-only truck lanes) should be studied.

To enable automated driving, creating a favorable policy environment is the most important initial move for road operators, particularly with respect to following distance rules. For instance, Florida’s law states that trucks must maintain a minimum following distance of 300 feet. State officials in such situations may want to consider changing such overly-specific language to accommodate truck platooning and gain the associated societal benefits.

IX. Regulatory and Policy Considerations

IX.A. Federal / State Roles
The government / industry relationship for the deployment of new vehicle technologies has proven to be acceptable in terms of effectiveness and safety. Examples include the rollout of anti-lock braking, and driver aids such as cruise controls and crash avoidance.

The relationship is complex. There is no procedural handbook. Various government agencies and industry organizations are stakeholders. They collectively address the safety standards, engineering specifications, compliance and enforcement.

The Federal government regulates specific performance, equipment and design features on new vehicles. Responsibility for operation of passenger vehicles is a state responsibility (however, NHTSA has leverage to obtain certain policy goals – such as seat belt use – via funding). Responsibility for operation of commercial vehicles is a state responsibility, with specific aspects Federal (FMCSA).

It is possible that NHTSA will issue Federal Motor Vehicle Safety Standards relating to AV. No definitive statements on this point have been made by the Agency. In the absence of FMVSS, at the federal level AV operation is legal, as vehicle regulations in the U.S. follow the principle of “anything not prohibited is permitted.” The industry should consider the pros and cons of regulations and take action as needed.

For operational reasons, it is important to avoid a situation in which different states have significantly different operational regulations for AV’s. Vehicle manufacturers may petition for national regulation to avoid having to meet regulation by individual states. The trucking industry should examine existing laws for any stipulations that would impede progress towards automated vehicles operating safely on the nation’s roads.

IX.B. Certification of Vehicles
Based on precedents to date, certification is expected to be the responsibility of the OEM and their suppliers. Industry organizations (i.e. SAE, IEEE, TMC) will likely set engineering standards and recommended practices upon which this certification may be based.
It is of note that, as part of road demonstrations and testing activities already conducted for DATP systems, states such as Nevada have not been requiring special registration of DATP equipped trucks since the system represents only Level 1 automation. Nevada’s automated vehicle testing and deployment rules focus on systems with automation of Level 2 or higher and other States considering vehicle automation rules seem to be following a similar framework, consistent with NHTSA guidance.

Nevertheless, there should be clarity as to any fleet responsibility for getting (or keeping) the vehicles certified.

**IX.C. Insurance and Liability**

**IX.C.i. Insurance**

Automated driving, while designed to eliminate human error and thus reduce road crashes, creates a new challenge to the insurance industry. Most accidents are caused by human error. The error can be the responsibility of the passenger car or commercial vehicle driver. It is estimated that mechanical or electrical issues with the vehicle are at fault in approximately 11% of crashes.

The higher levels of AV technology, by its very nature, removes the driver from being in error. Therefore, responsibility will mostly likely shift to the vehicle manufacturer.

As automated driving technology gradually becomes standard, insurers will be able to determine the extent to which this technology reduces the frequency and cost of accidents. The insurance companies will be able to determine whether the accidents that do occur lead to a higher percentage of product liability claims, as claimants blame the manufacturer or suppliers for what went wrong rather than their own behavior.¹⁸

In California, the Association of California Insurance Companies is advocating “for changes clarifying that the autonomous vehicle’s manufacturer retain all liability for damage, losses or injuries caused by the operation of these vehicles as required by the enabling law (SB 1298),” according to Property Casualty Insurer’s Association of America. Other states have considered such proposals. Approaches to manufacturer liability must also be addressed in the case of fleets which are self-insured.

In contrast, the trucking industry is insured by "commercial" insurance carriers, rather than "personal auto" insurers. Developments with personal auto insurers may influence the insurance picture for trucking but the differences are significant. Personal insurers classically offer front-end discounts for a variety of safety and security systems whereas commercial insurance typically does not offer any front-end premium discounts for technology adoption or other safety programs. The business model assumption is that crash and safety events will go down through the use of proven safety strategies, leading to an improved experience rating and safety record for those carriers.

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IX.C.ii. Liability
US DOT statistics show that the critical causal factor in the majority of car-truck crashes resides with the car driver. However, due to inequities in tort law formulas, most states utilize civil litigation formulas whereby a motor carrier has substantially more financial liability than negligence when a multi-vehicle crash occurs. This has created an extremely risk averse trucking industry.

Passenger car OEM legal experts have stated that the existing liability law structure is sufficient for AV technology to proceed into the market. Some manufacturers have indicated they are willing to bear the liability for any incidents which are the fault of their technology and which occur during the portions of a trip under full automated control. This industry willingness is bolstered by the “black box” capability of many automated control systems, which can record data indicating fault in the event of a crash. However, as noted above, the risk of civil litigation for trucking fleets raises the stakes substantially.

IX.D. Hours of Service
Automated driving could have an impact on commercial vehicle "hours of service" at the point at which the driver's role in “driving” is minimal or non-existent. Such capability is not expected to be available for trucks for at least 10 years. Therefore this issue is beyond the scope of this paper.

IX.E. Enforcement
It is anticipated the FMCSA will oversee all safety and regulatory requirements relating to automated driving of trucks, as well as improving safety information systems, and increasing safety awareness. However, enforcement of safety regulations is conducted at the state and local law enforcement level – which creates challenges with standardizing enforcement activities.

Discussions with FMCSA and organizations like CVSA will be important early on, to identify issues and approaches.

X. Recommendations

X.A. Recommendations for TMC
a. Conduct a review of the benefits and impacts of near-term platooning systems to develop guidance for system developers (building on the contents of this paper).
b. Assess any barriers to various forms of truck automation, particularly in terms of state/Federal regulations.
c. Establish an expert consensus on the amount of fuel savings potential for various following distances.
d. Assess the degree to which technicians need to be trained and/or certified to maintain DATP systems
e. Hold discussions with the enforcement community to assess enforcement issues for near term automated driving systems.
f. Closely track industry developments to introduce Level 2 (and higher) automation systems.
g. Develop "Guiding Principles" for near-term platooning and early forms of independent automation, building on the contents of this paper.
X.B. General Recommendations for the Heavy Truck Industry

a. As needed, prepare model legislation for states on operation of near-term truck AV systems.

b. Assess current insurance approaches for suitability for increasing levels of automation. Work with insurers to develop new models as needed. Address the particular needs of self-insured fleets.

c. Assess and facilitate public acceptance of near term truck AV systems.

d. Some specific technical and scientific evaluation areas are:
   
a. Determine the time needed for a commercial vehicle operator to re-attach to the driving task in event of a system failure in a highly automated commercial vehicle. This reattachment period could be different than the operator of a passenger car.
   
b. Study truck driver's capability of controlling a vehicle with minimal following distances for long periods of time while experiencing the lack of a large field of view, especially behind a van trailer. Such studies should assess the issues and also investigate means of countering any negative effects.
   
c. Assess what overall vehicle design characteristics can be modified to maximize fuel savings in platooning. For example, the optimal aerodynamics package for independent operation may be different when drafting in a platoon.
   
d. Investigate the pros and cons of adding lateral control to near term truck platooning systems. In particular, assess the need for lateral control or lanekeeping to allow closer following distances, thereby further improving fuel economy.
   
e. For near term truck platooning, traffic impacts should be examined across various levels of market penetration, across light and heavy truck traffic corridors, and across platoon length.
   
f. Analyses should be conducted to estimate the likelihood of passenger vehicle cut-ins between platooning trucks, for various platooning following distances.
   
g. Once traffic impacts are understood, road operators should examine different rules on different corridors, if this fulfills policy goals for traffic and freight efficiency. For instance, road segments serving ports might allow longer platoons than the overall road network.

X.C. Technology Demonstrations

Technology Demonstrations are essential for fostering cooperation between all stakeholders, suppliers, regulators, insurance companies, states and commercial fleets. A national approach should be developed to gain experience through on-road testing and open the way for deployment of near-term platooning systems if test results are positive. This should be done by region or state in order to get widespread buy-in, and should include many vehicle manufacturers, suppliers, and fleets.

It is notable that a growing number of States are showing strong interest in hosting demonstrations and fleet pilots. Several are actively working to arrange their own truck platooning projects or to host private sector demonstrations and fleet pilots. This should be encouraged.
Appendix One: Government Perspectives and Programs

USA Federal Government

NHTSA 2013 Policy Document on Automated Driving
NHTSA issued this statement to help states implement AV technology safely so that its full benefits can be realized. The document defined five levels of automation, described envisioned research, and discussed technical challenges such as human factors, reliability, cybersecurity, development of system performance requirements, and defining test and evaluation methods.

While recognizing many unanswered questions regarding AV operation, NHTSA affirmed the potential benefits of AVs. Given the relatively early stage of development, NHTSA recommended states not permit operation of “self driving” vehicles for purposes other than testing, which appears to refer to Levels 3 and 4. The agency provided a set of recommendations for states:
- licensing drivers to operate AVs for testing
- developing state regulations governing testing of AV’s
- basic principles for testing

ITS Strategic Plan
In 2014, USDOT’s Intelligent Transportation Systems Joint Program Office published an ITS Strategic Plan for 2015-2019. The plan has two strategic priorities: Realizing Connected Vehicle Implementation and Advancing Automation. Under these are five strategic themes and six program categories.

Strategic themes:
- Enable Safer Vehicles and Roadways
- Enhance Mobility
- Limit Environmental Impacts
- Promote Innovation
- Support Transportation System Information Sharing
- Automation

Regarding the automation theme, USDOT noted that “these technologies offer tremendous possibilities for enhancing safety, mobility, and the environment, but also pose new technical and policy challenges. The focus of the ITS Program in this area will be on the advancement of technology and systems to enable smooth and safe introduction of automated features into the nation’s vehicles and transportation systems.”

The Program Categories are:
- Connected Vehicles
- Automation
- Emerging Capabilities
- Enterprise Data

• Interoperability
• Accelerating Deployment

Europe

European Commission
The EC has funded significant work in automation and several projects are ongoing (see projects section). The Horizon 2020 Workplan 2014-15 for Transport includes the following topics for AV R&D which “support gradual progress towards full automation:”
  • Dedicated supporting technologies for individual pre-emption or compensation of human errors, or even taking over the vehicle control in case of imminent collision. This could include:
    o Advanced Driver Assistance Systems (ADAS) to support drivers in accident avoidance and to mitigate the consequences of collisions, including tools to detect and measure undesirable or unusual driver condition (such as drowsiness) and warn, control and correct that behavior at different levels;
    o better optimized Human Machine Interfaces (HMI), providing tailor-made information which the driver is capable of processing in continuously changing conditions.
  • Novel transport, service and mobility concepts in real-life situations enabled by automated driving and connectivity.
    o These services and concepts could benefit from cloud computing and data management and data aggregation techniques for road transport big data.
    o They could also include automation specific to the road freight sector, including smart, secure on-board and infrastructure based-systems and seamless integration with other modes. In this context, particular attention could be given to demonstrating freight services/road trains. Attention should be paid to understanding and addressing the responses of users.
  • Dissemination and take-up of results, including the development and consensus building on business models to progress towards full automation in road transport.
  • Liability and standardization policy and regulatory framework recommendations
  • International cooperation in research and innovation

United Kingdom
In 2013 the United Kingdom Department for Transport conducted a feasibility study regarding a truck platooning field operational test. The government is currently considering initiating such a test in 2015.

Regulatory Considerations
European countries are signatories to the Vienna Convention. The Road Traffic section of this document, written before AV’s were envisioned, present some roadblocks to AV operation on EU roads. (The U.S. is not a signatory to the Convention.) Further, UN Economic Commission for Europe (ECE) defines additional factors which may limit AV’s. The industry is working with government to potentially amend these documents.

Briefly, the issues are as follows:
  • Every moving vehicle must have a driver, who shall be able to control the vehicle at all times (Vienna Convention)
  • Drivers shall at all times minimize activities other than driving (Vienna Convention)
• Drivers shall at all times be able to perform maneuvers required of them; when adjusting vehicle speed they shall pay attention to the surrounding situation; they shall slow down and stop when circumstances require.
• Automated steering above 10 kph is not allowed (ECE Regulation 79)

Proposed amendments, which have not been ratified yet, call for language similar to the following:
• Vehicle systems shall be considered as in conformity with the regulation when they can be overridden or switched off by the driver.

It is currently not clear if or when new amendments and interpretations will be in place to clear the way for AV operation; however there is significant industry activity to accomplish this.

Japan
Japan has been active in AV R&D since the 90’s but until recently had their strongest focus on V2X. However, during the 2000’s, the Japanese government conducted a major program to examine automated truck platooning under the Energy ITS program. Public road testing has been underway in Japan for AV’s since 2013.

Now AV research and deployment is one of a small number of high profile national strategic initiatives. The work includes both passenger cars and trucks. Government-industry collaborative topics within their AV Strategic Innovation Program are:
• driver model
• system security
• dynamic map: Dynamic Map Structuring Task Force

Additionally, preparations are underway for the 2020 Olympics in Tokyo; the government plans to implement next generation Urban Transportation Systems. This is considered the first milestone of launching automation into the megacity.

Appendix Two: European Industry Association View
The International Road Transport Union (IRU), representing commercial trucking in Europe, issued a draft policy document in 2013 addressing automated driving. Their Commission for Road Safety concluded that the efficient introduction and implementation of autonomous mobility within the road transport industry should address the following issues:
  a. national road traffic rules and international road traffic conventions shall be duly amended so to allow the circulation of experimental vehicles in order to facilitate the research and development of new ADAS technologies.
  b. cost/benefit analyses shall be based on an integrated approach with global coverage and clearly demonstrate an added value for society in terms of road traffic safety;
  c. cost/benefit analyses should clearly demonstrate an added value for society in terms of decreasing environmental impact;
  d. no monitoring by authorities, or distance control by local enforcement authorities;

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e. any implementation should be carefully analyzed in order to avoid any misinterpretation of market needs and adverse consequences on transport as a whole;

f. V2X communication is likely to become an enabler of autonomous driving/vehicle.

g. determine which V2V, V2I, V2X technologies will be required for all vehicle categories operating on all markets;

h. systems must be standardized, harmonized and interoperable in order to improve the effectiveness, safety, security and reliability of transport as a whole;

i. retrofitting of existing vehicles should not be mandatory whilst voluntary retrofitting should be encouraged with appropriate uptake measures by authorities;

j. systems must provide data security to meet all legal terms. This concerns external access to the individual vehicle, and also the transfer of data for V2V and V2I or Internet communication.

k. systems must encompass all liability issues such as traffic infringements and accidents.

l. all stakeholders in the transport chain should retain freedom of choice of the means of transport they use and in selecting ITS equipment and application suppliers;

m. systems should be coupled with the use of transport documents available in electronic format;

n. one should ensure an appropriate level of confidentiality of commercial data to guarantee that vehicle locations and information, i.e remote access vehicle data are in conformity with regulations on data protection, including when used in intermodal transport chains; this vehicle communication technology will also face a public acceptance challenge, due to concerns about privacy;

o. one should consider necessary training for platforms networking within a multi-actor traffic environment;

p. one should include a solid business case, demonstrating the benefits and the costs involved to all stakeholders; and

q. one should provide appropriate incentives in the business plan to ensure take-up by the users.

Appendix Three: Current Government-Industry Research Projects

The latest round of publically-funded research on AV's in the U.S. ramped up in 2013, starting with a NHTSA project evaluating human factors aspects of L2 and L3 automation. This was followed with FHWA-sponsored work in both car and truck platooning (focused on both mobility and fuel economy benefits). NHTSA also funded the OEM consortium CAMP to examine functional descriptions and test methods for emerging AV applications for passenger cars. More work is expected to get underway in 2015.

In Europe, several car- and truck-focused AV projects are underway, notably ADAPTIVE and COMPANION. The first field operational test of regular drivers in near-production cars, called Drive-ME, is in its preparation phase in Sweden. More projects are expected to start by late 2015.

Japanese work continues under a new comprehensive automated driving program encompassing passenger cars, commercial trucks, and transit.

More information follows on specific projects. Some passenger car projects are profiled as the results may apply to truck automation as well.
NHTSA: Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts

This passenger car focused project was led by the Virginia Tech Transportation Institute and included GM and Google as participants. The project includes development of Human Factors Guidelines for automated vehicle design. The experiments have been completed and the final report is expected to be released in 2015.

The research addressed the following human factors questions:

- What is the driver performance profile over time in sustained (longer term) and short-cycle (shorter term) automation?
- What are the risks from interrupting the driver's involvement with secondary tasks when operating a Level 3 type automated vehicle?
- What are the most effective hand-off strategies between the system and the driver including response to faults and failures?
- What are the most effective human-machine interface concepts, guided by human factors best practices, which optimize the safe operation?

Two significant documents have been published from the NHTSA Human Factors project:


The project includes the development of human factors guidelines for AV developers based on the research results.

The full project report is expected to be released by NHTSA in 2015.

FHWA/Auburn University: Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment

This $1M project focuses on Driver Assistive Truck Platooning (DATP) focusing on two-truck platoons. The project participants are Auburn University (lead), Peloton Technology, Peterbilt Trucks, supplier Meritor WABCO, and the American Transportation Research Institute (ATRI).

This project is a deployment-focused investigation serving to bridge between previous full platooning research and key factors needed for the trucking industry to begin DATP operations and gain the associated benefits. Phase One of the project focuses on defining an operationally and technically feasible system for industry. Phase Two builds on Phase One results to implement a prototype system that meets the user needs and can have maximum positive impact on freight efficiency and mobility. Phase Three focuses on transitioning research results to industry, to include a system validation plan that will guide test and evaluation. This project uses simulation, track testing, and finally highway testing to iterate on strategies for system definition.

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The key research objective is to define a commercially viable DATP system, in both operational and technical terms. Such a system (drivers are responsible lateral control (steering) of both lead and following vehicles at all times) must have effective operational strategies for real world conditions such as finding and coordinating with linking partners, making and maintaining the link, and delinking (by driver choice and when a system fault/limitation occurs). The driver-vehicle combination must at all times react to events to ensure a maximally safe result, even in worst-case scenarios.

DATP may be attractive from a safety and cost of operations standpoint. In terms of safety, the radar-based system provides an additional level of situational awareness to the driver whether DATP is activated or not. Further, testing in past FHWA EAR research and by project partner Peloton has shown that, due to aerodynamic drafting effects, DATP has the potential to significantly reduce fuel use for both the trailing and leading trucks – road experiments have shown 10% and 4.5% improvements respectively. Therefore, this type of operation could significantly reduce cost of operations and fossil fuel consumption.

However, technology is only useful if it meets user needs. A CACC trucking operation, while relatively straightforward technically, constitutes a major step for fleet operators and drivers: depending on data from another vehicle for the safety of “my” vehicle. A wide range of questions arise, which are being addressed by the project: how can my driver find another equipped vehicle? How do I know the other vehicle is DATP-enabled? How robust is the system? Can the system adapt to changes in load? How will the following driver retain situational awareness? How does the job of the lead driver change? How does the system react to passenger car cut-ins and other anomalies?

Current status: Phase I is complete and the final report is available (which includes a Concept of Operations and System Requirements document); the Auburn team is actively seeking feedback on these documents from the trucking industry. Phase II is underway: the experimental vehicles arrived from Peterbilt in 2014, the DATP has been implemented and testing is underway on the Auburn test track. On-road evaluations will commence in late 2015.

The Phase I final report is available here: http://eng.auburn.edu/~dmbevly/FHWA_AU_TRUCK_EAR/FHWA_AuburnDATP_Phase1FinalReport.

FHWA / Caltrans & UC Berkeley: Partial Automation for Truck Platooning

This $2M project addresses Level 1 truck platooning (the follower driver is responsible for steering) with a focus on a specific deployment setting in California. The project team is shown in the chart.

Research questions address:
– Performance achievable with truck CACC in mixed traffic
– Driver preferences for CACC time gaps
– Energy savings at preferred time
gaps
– Benefits in truck lane capacity, energy and emissions
– Market attractiveness to fleet operators

Public policy issues address:
– Deployment strategies for truck CACC
– Synergy with I-710 truck lane development
– Attractiveness to public and officials

The target for deployment is for the Gateway Cities initiative focusing on freight flows to/from the port of Long Beach to an inland railhead, as shown in the chart.

Three Class-8 tractors will be equipped and tested (with trailers/chassis). Truck CACC will be implemented by adapting ACC product on these tractors. Researchers will conduct experiments to examine:

- Maneuvering (2014-15)
  - Tight control of gaps
  - Option to choose shorter gaps
- Users (2015)
  - Driver interface design based on simulator tests
  - Test driver preferences for gap settings (2015)
  - Human factors experiments with representative truck drivers
- Energy savings at preferred gaps (2016)

Stakeholder outreach is a key component of the project. Public demonstrations will occur in southern California and the D.C. area in 2016.

**Texas Transportation Institute Truck Platooning Study**

Level 2 truck platooning is an extension of cooperative adaptive cruise control that utilizes automated lateral and longitudinal vehicle control, while maintaining a tight formation of vehicles with short following distances. A platoon is led by a manually driven truck and allows the drivers of the following truck(s) to disengage from their driving tasks and monitor the system performance. Driving in a platoon formation has demonstrated the potential for significant fuel savings benefits and associated reductions in emissions from the vehicles within the platoon.

With funding from the innovative research program at the Texas Department of Transportation (TxDOT) and partnerships with private industry, the Texas A&M Transportation Institute (TTI) will create a first-of-its-kind comprehensive freight platooning demonstration in Texas. Building upon past and current platooning research projects, the TTI team strives to demonstrate the safety benefits, fuel savings, and emission reductions achieved by extending vehicle automation to freight truck platoons.

The project started in 2015 and is planned in three phases:

- Phase 1: Conduct a feasibility planning study and proof of concept demonstration.
• Phase 2: Develop the concept of operations and requirements for design.
• Phase 3: Deploy a commercial truck platooning application in Texas

Initial funding has been awarded for Phase 1, which will:

• Conduct feasibility studies: This portion of the project is designed to investigate and document lessons learned from past platooning projects; identify potential regulatory or legislative roadblocks that could hamper or facilitate introduction of platooning into commercial fleet operations; and explore the possible business cases and implementation scenarios within the existing infrastructure and operation environment. The tasks will focus on the feasibility of deploying 2-vehicle truck platoons on specific corridors in Texas within 5 to 10 years.

• Demonstrate the technology: This portion of the project includes developing, testing, and demonstrating the technology (proof of concept) and conducting a workshop to disseminate the results and capture insights and comments from the stakeholders.

**EUROPE: ADAPTIVE**
For this $29M project, the lead is Volkswagen with OEM partners BMW, Fiat, Daimler, Ford, Volvo Cars, AB Volvo, PSA, Opel, and Renault. The project runs from 2014-2017 and focuses on both passenger cars and trucks.

The project focuses on the applications of Highway Assistant, Urban Assistant, and Parking Assistant. Objectives are shown in the chart.

Of key importance is the sub-project RESPONSE4, whose objectives are to:
• Define steps towards a safe introduction of highly automated driving functions into the market
• Examine new risks for the manufacturer resulting from product liability
• Address protection against corruption and fraud of vehicle data and V2X data
• Address usage and protection of data collected by automated driving functions

Human factors work will:
• Collect research issues on the interaction of drivers with automation in vehicles that currently remain uninvestigated or unresolved.
• Conduct experiments in different laboratory settings, including dynamic driving simulators, and, if suitable, also instrumented test vehicles.
• Create functional requirements and decision strategies for collaborative automation in particular situations.

**EUROPE: COMPANION**
This is a $6.3M three-year project aiming at identifying means of applying the truck platooning concept in practice in daily freight transport operations. Major truck manufacturers involved in the project are Scania and Volkswagen.
Objectives are to develop a real-time coordination system to dynamically create, maintain and dissolve platoons, taking into account historical and real-time information about the state of the infrastructure (traffic, weather, etc.). The project includes demonstration of truck platooning operations on European roads in multiple countries starting in 2016.

**EUROPE: Drive-ME**
The Drive-ME project, led by Volvo Cars with the support of the Swedish government and city of Gothenburg, will deploy 100 automated Volvo cars in real traffic in 2017 with members of the public operating the cars.

**JAPAN: AV SIP Project**
AV research and deployment is one of a small number of national strategic initiatives in Japan. The work includes both passenger cars and trucks. Government-industry collaborative topics within their AV Strategic Innovation Program are:
- driver model
- system security
- dynamic map: Dynamic Map Structuring Task Force

The project activities are best described by this chart showing distinctions between government-industry collaborative work and other areas left to the industry to work out on their own.

**Appendix Four: Driver Considerations**
The automation technology provider must account for the impact of various driver issues when designing the capabilities and logic of the automation system. These driver issues will have influence on the effectiveness of the complete system.

More broadly, key issues with the implementation of the automation in heavy trucks will include trust, driver acceptance, training needs, and generational issues.

**Key Points**
For early forms of automation, key items are:
- The drivers must keep in mind that they are the prime control system no matter what the vehicle is capable of doing. While the vehicle may be able to operate without the driver’s hands and feet, the driver must understand that the electronic controls are to assist the driver in saving fuel and improving safety.
- At all times, it must be clear what degree of situational awareness the autonomous commercial vehicle has, and therefore in what situations the driver will be expected to handle.
- Drivers that slip seat between vehicles will have to be aware at all times of the features of the vehicles that they are driving. They must be aware of the abilities of the vehicles that they are currently driving. Two trucks of the same make and model may be equipped differently.
For higher levels of automation, additional issues arise:

- For passenger car operation, questions arise with Level three autonomy, where the vehicle is in control but the driver must be available to assume control if there is an issue with the autonomy. Will the passenger car driver actually be available when needed? It is possible that this level three autonomy is more plausible with a well trained and regulated driving population as is found in commercial vehicles.

- Driver state at authority transitions is a critical factor. Some system developers believe higher levels of AV technology creates a need to be able to discern the driver state at vehicle control authority transition points. At these transfers of control, the driver must be alert and cognizant of the current driving context in order to react properly in potential critical situations. Degraded driver alertness can be either unintentional inattention such as driver drowsiness or intentional inattention such as driver distraction. The presence of automation itself may enhance the onset of both of these inattention types. For instance, unintentional driver inattention or drowsiness might be heightened by the monotonous driving conditions. Also, the driver might perceive a decrease in workload during high levels of automation and cause the driver to engage in distracting secondary tasks in the vehicle. Reliable means of determining driver state, and its role in successful implementation of automated vehicle technology, is a key issue for the industry.

- With regard to the point above, driver incentives could usefully come into play for AV truck systems that involve driver engagement, such as platooning. The degree of driver adoption and their effectiveness in sustained use of systems could potentially be strengthened by various incentives.

**Workload**

The first driver factor is workload. Driver workload refers to the "competition in driver resources (i.e., perceptual, cognitive, and physical) between the driving task and a concurrent subsidiary task, occurring over the task's duration.”

Under typical driving, the driver may find at times the demands of performing multiple concurrent tasks challenging. Automation technology offers an opportunity to relieve the driver of these stressful tasks because the driver is taking on a more supervisory role in operating the vehicle. This assertion is supported by research using fully-automated and adaptive cruise control systems.

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Based on lessons learned from aviation, others warn that improper implementation of automation technology could negatively affect the workload of the driver especially under complex, dynamic driving conditions or system failure.

**Situational Awareness**

The next driver factor to be considered in the design of automation systems is situational awareness (SA). The term, SA, is defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future”. Situational awareness is vital for effective decision making especially in complex and dynamic contexts such as driving. Without sufficient situational awareness, the driver must make decisions based on missing or outmoded information which could lead to poor judgment and ultimately errors. Endsley (2012) states that there are three separate levels of SA:

- Level 1 – perception of the environmental elements
- Level 2 – comprehension of the current situation
- Level 3 – projection of future status

Automation technology providers must be cognizant of the information needed by the driver at each of these levels so the driver can appropriately progress through the three levels of SA. The subsequent levels build upon the understanding achieved at the lower SA stages.

The driver will perceive the elements of the environment through the five human senses. These environmental elements include the vehicle’s status via driver interfaces (e.g., displays and alerts), adjacent traffic, ambient conditions, and roadway features. The majority of issues with SA at this lowest level occur when the driver fails to detect the needed information. These elements might be missed because of the signal (i.e., obscured by other irrelevant information or improperly presented) or the driver (i.e., inattention due to distraction or drowsiness).

The driver will interpret the perceived environmental elements to gain an understanding the current situation, SA Level 2. In SA Level 3, the driver assesses the evolving situation to predict how it will change in the immediate future and determine an appropriate course of action. The driver’s understanding of current situation and projection of the future situation is dependent on the completeness and correctness of the information obtained in SA Level 1 as well as the driver’s experience and knowledge. Consider an inexperienced driver operating the vehicle in an unfamiliar setting. Although the elements in the environment have been noticed, the novice driver might not know how to interpret new elements or synthesize them into an appropriate action.

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33 Ibid.
Behavioral Adaptation
Another driver factor to consider in the driver’s ability to effectively operate an automated vehicle is behavioral adaptation. The concept of behavioral adaptation represents those unexpected or unforeseen changes in the driver’s behavior in response to modifications to the transportation system including the vehicle, roadway, or environment. These behavioral adaptations can manifest as changes in speed, change in following distance, way and frequency of lane changes, braking response, and change in level of attention. Research is needed to understand what behavioral adaptations the driving public will make with the introduction of automated vehicles. These adaptations could vary by level of automation and application type.

Potential Loss of Skill
Still another driver factor is the loss of skill. Because automated technologies are performing vehicle guidance tasks for the driver, the driver can become less practiced and skill atrophy can occur over time. In automation in aviation, Barley (1990) has suggested that pilots often deal with the problem of skills maintenance by periodically disengaging the automated system to restore their flying skills and/or relieve the monotony of long flights.

Driver Training
The degree of training needed will vary with each level of automation and each particular system. For instance, drivers accustomed to using Adaptive Cruise Control may adapt more quickly to truck platooning than those who are not.

Assessing the level of driver training needed, and the best methods for doing so, is an important industry issue. Potentially, for higher levels of automation driver simulators and closed test tracks could be useful so that drivers can become knowledgeable in the operations of these new devices.

Driver training can most likely be managed by industry working closely with fleets as is the case with training for other advanced safety and driver assistance systems, rather than via some form of regulatory / special driver licensing requirements.

Appendix Five: DATP: Analysis of Coordination for Linking
This appendix provides a more in-depth treatment of DATP than that found in Section VI of the main document.

Approaches to DATP pairing must be further clarified. Fleets may have to establish the rules of engagement, and/or inter-fleet platooning could be arranged on the fly using either V2V or cellular communications. The process has to be done in such a manner that the route, logistics, and safety are not compromised.

Auburn University performed a detailed analysis of the potential likelihood of pairing opportunities under the FHWA sponsored truck platooning project. The case study

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36 Auburn University, Partial Automation for Truck Platooning Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase I Final
analyzed truck fleet data to determine the impacts of platoon formation on several key metrics, including the number of platoons that may be formed from historical truck routes, the maximum size of any platoon formed, and the total time lost as a result of trucks slowing down to form a platoon.

The test data, provided by ATRI, captured the location of each truck in fleets who partnered with ATRI to share location information at various times of the day. Auburn University was provided two anonymized sets of data from ATRI, referenced below as "NDFT1" and "NDFT2," which contained data from several truck fleets. Each dataset describes individual truck locations that were recorded over an eight-day period along an approximately 300-mile long stretch of Interstate 94 between Dickinson and Fargo, ND. This particular road segment was chosen for the initial analysis due to its relatively low traffic volumes (resulting in a data set of manageable size) and limited ingress/egress points (allowing the consideration of trucks that remained on the corridor for an extended distance). Thus, this data set provided a means for testing and evaluating the optimization algorithms, while also providing insight into the impacts of platooning operations.

The analysis assumed that all of the trucks in the datasets are platoon eligible. New optimization algorithms were developed that determine which trucks should join to form a platoon, given the starting location of each truck. In particular, the analysis provided preliminary insights into the following metrics:

• Percent of trucks that join a platoon,
• Number of platoons formed,
• Number of trucks that were time delayed due to platooning operations,
• Number of platoon formation operations (number of times vehicles adjusted speed to join a platoon),
• Maximum platoon size at any given time (this analysis allowed for platoons greater than two trucks)
• Total time lost for trucks that platoon,
• Distance traveled within platoon by individual trucks,
• Percent of total distance traveled within a platoon, and
• Total (estimated) fuel savings resulting from platooning.

For the analysis, “adjustment speeds” were defined, i.e. a truck ahead of a potential partner slows, or the upstream truck accelerates, in order for them to meet.

From the results, several interesting observations can be made. First, the percentage of fuel savings is only sensitive to the assumption as to the degree of fuel reduction and road saturation. This is the most surprising result, as the average fuel savings is approximately 4%-7% regardless of the maximum allowable platoon size and adjustment speeds. It appears that the advantages and disadvantages of the parameters are normalized in the savings output. Second, the lead truck adjustment speed has a significant influence on the number of platoons formed. In particular, an increase in the lead truck adjustment speed (deceleration) results in the formation of additional platoons. However, a large lead truck adjustment speed also corresponds to increased time delays for platooned trucks.

One surprising result is that a trail truck adjustment speed of zero results in a greater number of platoons formed than when the trail truck speeds up by five miles per hour. The

Report. Available at:
http://eng.auburn.edu/~dmbevly/FHWA_AU_TRUCK_EAR/FHWA_AuburnDATP_Phase1FinalReport

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reason for this is that the cost of speeding up is a steep enough fuel consumption penalty to restrict platooning opportunities. However, a trail truck adjustment speed of five miles per hour enables longer distances traveled within a platoon by catching up to the platoon faster. A larger trail truck adjustment speed also decreases the time delay associated with platooning.

One of the core project research questions addresses the relative likelihood that trucks will be able to find platooning partners, given typical distributions of trucks on highways. This analysis found that, with this real-world dataset (which does not include all trucks on this highway section), formation of two-truck platoons among platoon-eligible trucks was 3-7% for NDFT1 and 30-45% for NDFT2. The specific percent formation within the ranges depended on the parameters employed by the platoon formation model (e.g., allowable adjustment speeds for leading or trailing trucks). Further, researchers found that trucks forming two-truck platoons in the NDFT1 dataset traveled within a platoon between 30-60% of the distance of the 300-mile road segment, on average. Trucks joining two-truck platoons in the more densely populated NDFT2 remained within a platoon between 55-75% of the road segment, on average.

Next phase work will incorporate differences in fuel economy benefits depending on platoon position. Therefore the results presented here should be considered preliminary.