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Heavy vehicle automation: Human factors lessons learned

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Abstract

Although passenger car automation has captured the public's attention in recent years, heavy truck automation has also been a major research topic around the world. In the U.S., the California PATH program at U.C. Berkeley has been engaged in heavy vehicle driver assistance and automation research for trucks, buses, and snow removal equipment for over 15 years. Until recently, much of the human factors work in the field has been limited to driving simulations because the state of the technology is only just now reaching the level of maturity required to move beyond pure research. Despite still being in the early stages of gaining practical, real-world experience with automation, lessons have been learned over the past two decades of heavy vehicle automation development. With the many different automation concepts being discussed, there are bound to be differences between passenger car and heavy vehicle automation because the motivations for automation differ between the two industries, resulting in different automation use cases and potentially leading to different design solutions. Similarly, since heavy vehicles tend to be engaged in commercial operations, institutional considerations can influence design, but commercial fleets also provide opportunities for driver training that might not otherwise be possible with the general public. Finally, the special use cases for heavy vehicle automation can challenge conventional design wisdom, and not all designs or conclusions coming from passenger car experience will necessarily apply to heavy vehicles.

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Keywords: Automated vehicles; Autonomous vehicles; Self-driving cars; Heavy vehicles; Trucks; Buses; Intelligent transportation systems; ITS; Truck platooning; Automated bus docking; Cooperative adaptive cruise control; CACC

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1. Introduction

Automated carshave captured the public's attention in recent years after Google announced its automated driving program in 2010, but vehicle and highway automationresearch has been active in the U.S., and around the world, since the concept of road vehicle automation was first introduced at the 1939 New York World's Fair's Norman Bel Geddes Futurama exhibit [1],sponsored by General Motors (GM). The first national automated highway system research program in the U.S. wasnot formed until 1991, as part of a congressional mandate in the Intermodal Surface Transportation Efficiency Act (ISTEA), and the National Automated Highway Systems Consortium (NAHSC) was created in 1994, led by GM. The work culminated in a 1997 demonstration of vehicle-highway automation in San Diego, CA. Vehicle automation research hassince gone through several cycles of progress and retrenchment, with the most recent resurgence coming from the Defense Advanced Research Projects Agency (DARPA) Grand Challenge (2004, 2005) and Urban Challenge (2007). The Grand Challenge focused on off-road vehicle automation, while the Urban Challenge focused on lower speed, urban settings with both traffic and traffic control devices. While therecent publicity surrounding vehicle automation has focused mostly on passenger cars,heavy vehicle automation has alsopersisted as major research topic,both in the U.S. and around the world [2,3].

In Europe and Japan, there have been quite a few truck automation research programs including CHAUFFEUR [4,5], SARTRE [6], the HAVEitAQuA concept [2,3], KONVOI [7], Energy ITS [8], and most recently, the European Commission's COMPANION project [9].In the U.S., heavy vehicle automation research has included both military [10] and commercial applications. On the commercial side, the California PATH program at U.C. Berkeley has been engaged in driver assistance and partial vehicle automation systems research and developmentsince the end of the NAHSC program, on both cars and heavy vehicles,including trucks, buses, and snow removal equipment [11, 12, 13, 14, 15].However, most of the work on heavy vehicle automationhas focused on demonstrations of the technology, the optimization of vehicle control strategies and algorithms, and the potential benefits of truck platooning in terms of fuel and emissions savings.While the potential human factors issues that could arise from vehicle automation have been speculated upon since the early 1970's [16], the majority of published human factors studies on the topic of vehicle automation to date have been mostly limited to surveys, focus groups, driving simulation studies, and the occasional test track or otherwise highly controlled experiment because the state of vehicle automation technology to date, especially pertaining to heavy vehicle automation, has not been ready for comprehensive, real-world, human factors testing.

Essentially, we are still in the early stages of gaining practical, real-world, experience with heavy vehicleautomation, but some lessons have been learned from prior research, and the goal of this paper is to highlight some of the potential differences between heavy vehicle and passenger car automation concepts. First, there are differences in the basic motivations for vehicle automation between passenger cars and heavy vehicles, and the different motivations can lead to different use cases that must be considered. As an example, the drivers of passenger cars are motivated by the expectation that automation will free them from the tedious driving tasks and allow them to engage in tasks that would normally be considered a distraction [17, 18, 19]. Conversely, the primary motivation for automation in heavy vehicles is largely economic, promising increased productivity, decreased fuel consumption, and minimizing losses due to avoidable crashes. Second, since heavy vehicles are generally used commercially and as part of a fleet, institutional considerations may influence design and implementation.Finally, since the motivations differ between passenger car and heavy vehicle automation, a number of special use cases must be considered when designing of heavy vehicle automation, but may not ultimately apply to passenger car automation. Given these considerations, not all designs or conclusions coming from passenger car automation will necessarily be fully applicable to the design of heavy vehicle automation.

2. Motivations for heavy vehicle automation

2.1. Safety Motivations

Although safety is a shared motivation for passenger cars and heavy vehicles, there are differences in the kinds of crashes and factors associated with those crashes between passenger cars and different types of heavy vehicles. As an example, a recent study looking at car-truck crashes in the National Motor Vehicle Crash Causation Study

(NMVCCS) found that the passenger cars were more likely to be the encroaching vehicle in the crash, and 71 percent of the critical reasons for the crashes were assigned to the car, rather than to the truck. Furthermore, driver factors such as fatigue, impairment, or aggression were more frequently associated with the driver of the passenger car, while vehicle factors, such as equipment failures and maintenance issues, tended to be more frequently associated with the truck [20]. Thus, the capabilities, requirements, and design of the automation systems for heavy vehicles need to start with understanding the crash scenarios encountered in these types of vehicles, especially in lower levels of automation such as Level 2 as defined in SAE J3016 [21], wherein the driver retains a large portion of the responsibility for monitoring the roadway and traffic conditions. Simply automating the speed control and steering, while leaving the driver in charge of speed selection and monitoring, may have a much larger impact on passenger car safety, where 16 percent of all crashes were associated with some form of distraction [22], but less of an impact on truck crashes, where the top three critical reasons leading to single vehicle truck crashes included driving too fastfor conditions or curves, falling asleep at the wheel, and vehicle component failures or cargo shifts [23]. For the automation system to have an impact on some of the key truck crash scenarios, the system requirements may need to include speed advisories, automatic speed adjustments, driver alertness monitoring, and even a safe stop ability should the driver become non-responsive.

2.2. Economic motivations

Because heavy vehicles are generally engaged in commercial activity, the primary motivation for adding any equipment to the vehicles will belargely based on the economicgains that can be achieved, balanced with the cost of the system. The economic benefits might come from increased worker productivity or decreased labor or fuel costs. As an example, the automation systems might prove useful, after careful study, in providing a basis for relaxing the driver hours of service requirements. Alternatively, the automation systems might allow fleets to reduce the number of required drivers using SAE Level 4 systems that can simply operate without a driver or using a more limited system as envisioned with the electronic tow-bar concept, where a driver would only be required in the lead truck (and the route only included freeway driving). The electronic tow-bar concept has been discussed in the CHAUFFEUR, KONVOI, and SARTRE projects, and there may be opportunities for nearer term deployments using more limited automation systems wherever freight is being moved from one port or rail terminal to another.

For trucks, the potential for reduced fuel consumption provides another economic benefit. At highway speeds, fuel consumption is significantly influenced by air resistance, and the shorter following gaps (in the 6 to 10 m range) that can be enabled through cooperative automation can yield energy savings potentially as high as 20% to 25% [8, 24, 25, 26, 27, 28]. With an average fuel economy of 5-7 miles per gallon, even modest improvements can lead to large cost savings for fleets with thousands of trucks each logging hundreds of miles per day. While there has been some work on connected automation to improve passenger car fuel economy through platooning, the fuel savings achieved was only around 10% [29, 30], and since the savings would only apply to a single driver, the case for automation based on improved fuel efficiency may not be as compelling. Thus, platooning may be a requirement for the adoption of heavy vehicle automation, but not necessarily for the adoption of passenger vehicle automation.

For buses, and in some cases trucks, economic motivation might also come from reduced infrastructure costs and increased operating efficiencies. Automation, particularly lane assist, can allow vehicles to operate in narrower lanes and perform difficult driving maneuvers more easily, so when planning to build transit or freight lanes, the ability to operate in narrower lanes can significantly reduce the infrastructure costs [31]. Automated bus docking to a boarding platform at each stop can also increase operating efficiency by allowingfaster and more convenient passenger loading and alighting. Similarly, automation can allow buses and trucks to traverse narrow toll plazas at higher speeds, thereby decreasing travel times and minimizing the likelihood of vehicle damage where the infrastructure is less than optimized for heavy vehicles. All of these motivations can lead to very different operating environments and vehicle maneuvers than would be expected of passenger car automation.

2.3. Motivations arising from heavy vehicle special use cases

Heavy vehicle automation can be motivated by any number of special use cases or challenging driving environments. Automated convoys of military vehicles might include a wide range of specialized heavy vehicles traversing an even wider array of terrains and hazardous conditions [10]. Another example of specialized automation is snow removal equipment. To keep the roads passable, snow plows must sometimes operate on mountainous roads, in the middle of stormy conditions, with limited visibility, and while avoiding invisible hazards such as parked cars that are buried under the snow. Hitting an abandoned car with the blade of a snow plow or even hitting buried guardrails can cause damage to both the plow and the infrastructure. One of the key lessons learned in trying to build snowplow operator assistance and automation was that the tasks required of the operators and vehicles are not as simple as driving down the center of the road. The operators often work in various team formations, with each plow maintaining specified offsets from the roadway centerline [13, 14]. When designing automation for these specialized use cases, conducting user needs and task analyses are criticalin determining the kinds of features, displays, and feedback that will be most useful.

3. Institutional considerations

3.1. Organizational influences on design requirements

In designing heavy vehicle automation systems, institutional factors can also play a large role in influencing the system requirements and even the driver interface design. As discussed previously, the motivations to implementautomation in a fleet can vary and can lead to different use cases that must be considered, and often, the person in the fleet who is tasked with considering which systems to purchase is not going to be an end user of the system. With passenger vehicle automation, the primary driver of the car will most likely be the person who evaluates the technology and ultimately selects their desired vehicle. With heavy vehicle automation, the drivers who will use the automation systems may have little say in the selection of, or requirements for, those systems. Fleet owners and managers will be the ones who dictate which system requirements, features, and cost restrictions will carry the mostweight during the evaluation process.

The organization can also influence the system and driver interface design decisions in unexpected ways. In a PATH project to implement and evaluate a transit Forward Collision Warning (FCW) system, the organizations involved in the system testing highly discouraged the use of auditory warnings [32], even though most passenger car FCW systems rely primarily on auditory warnings. In the transit environment, auditory warnings can easily be heard by nearby passengers and there was concern that frequent alertscould potentially annoy their customers. There was also a fear that an audible alert, followed by a rapid deceleration, could be used as evidence in cases when a passenger falls and is injured, or worse, the audible alert could allow a passenger to stage a fraudulent injury case.

Similarly, in the development of driver-vehicle interfaces for the partial automation for a rotary snow plow [15] and for a bus docking implementation [31], the organizations involved in the system testing set a high priority on maintaining the driver's focus on the road while the automation was engaged and minimizing any training necessary to understand the system operation. In both cases, follow-up focus groups with drivers generally agreed with these principles and with minimizing the amount of information that a driver-vehicle interface should try to convey about the system status and operation. The favored designs that were eventually implemented used a series of simple colored LEDs (red, green, and blue) to convey system state, rather than an LCD screen withmore complex and flashier graphical displays, such as those typically preferred by passenger car owners and drivers.

3.2. Driver training

There are also organizational advantages for heavy vehicle automation as compared to passenger car automation. One of the key issues that arose when the state of California began drafting regulations for the testing and deployment of automated vehicles on public roads centered on driver training [33]. The discussion focused on whether it was reasonable to expect manufacturers or dealers to train drivers on how to use the automation systems they purchase, when dealers may only get to spend an hour with a new car owner to cover all of the features on the car. In a PATH study on Adaptive Cruise Control (ACC), when potential test participants who own an ACC-equipped vehicle were contacted, a surprising number of them were completely unaware of the feature or had never bothered to learn how to use it. However, since heavy vehicles are generally part of a fleet, these organizations have the opportunity to promote a safety culture, establish driver training programs for new technologies, and incorporate additional training through continuing education programs, all of which might not otherwise be practical or possible when passenger car automation is introduced. In a PATH project on the development of transit FCW systems [32], driver training on how to use the system was incorporated into the driving simulator training already provided by the agency on an ongoing basis, allowing the drivers to experience the system in action. In a recent PATH project deploying automated lane keeping in a transit environment, a small test track was set up in the maintenance yard to help train drivers. If these kinds of resources are available, fleets may even be able to train drivers to better handle infrequent events, such as system failures, since driving skill degradation is a common concern when discussing the widespread propagation of vehicle automation.

4. Heavy vehicle design considerations

4.1. Driver role

One of the most discussed automated driving issues or concernsacross all vehicle types is clearly defining the roles and responsibilities of the driver for a given system, and there are likely to be distinct differences in these roles and responsibilities for the heavy vehicle and passenger car drivers. As defined in SAE J3016 [21], an SAE level 1 system, ACC or lane assist, would still require the driver to maintain the role of actively controlling one aspect of the vehicle control. An SAE Level 2 system would not require the driver to actively control speed or steering, but would require the driver to actively monitor the roadway, and SAE Levels 3, 4, and 5 allow the driver to disengage from actively monitoring the roadway. While the motivations for passenger car automation, the ability to mostly or completely disengage from the driving task, necessitate higher levels of automation, some of the compelling use cases for heavy vehicle automation, such as automated bus docking and truck platooning, could potentially yield enough benefits to warrant their implementation with lower levels of automation.

It is even possible that automation will add additional tasks and additional responsibilities to the drivers of heavy vehicles. As an example, truck platooning will add coupling and decoupling procedures, and the lead driver in a truck platoon could be burdened with additional monitoring responsibilities while leading the platoon such as monitoring the roadway for hazards that can’t be detected by the automation sensors or monitoring the status and requests made by other trucks within the platoon or wishing to join the platoon. Since heavy vehicle drivers already perform many duties in additional to driving (interacting with dispatchers, rerouting based on traffic conditions, regulatory documentation of hours of service, or interacting with passengers), the entire spectrum of driver responsibilities, task flows, and workloads will be considered as use cases in the design and development process.

4.2. Physical considerations

The physical considerations of the heavy vehicle cab and seating and the characteristics of the driver population will also play a role in design of the automation driver-vehicle interface. As shown in Fig. 1a, truck cab instrument panels are already much more crowded with controls and displays than a typical passenger car, and often these fleet vehicles include supplemental systems for fleet operations, creating competition for both real estate and driver attention. Transit buses can be even more constrained, with even less adjustability of the driver seating position, and when combined with drivers in the upper end of the population size range, often wearing heavy or bulky clothing, there can be unexpected design concerns. As an example, typically, the automation of the steering function would allow the driver to override the system by applying torque to the steering wheel. However, as shown in Fig. 1b, when the automation turns the steering wheel, it’s possible that the resistance of the steering wheel rubbing against the driver’s clothing could be sensed as an intentional override causing the system to disengage. This problem can be further complicated when driver’s typical duties include tasks that require extreme reaches or when the combination of vehicle suspension and operating characteristics (such as rough terrain) makedriver body contact a

b

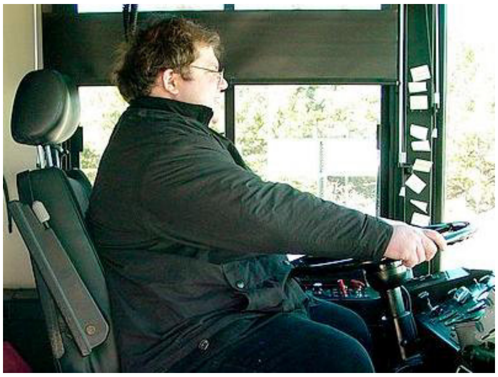

Fig. 1. (a) 2015 Volvo VNL 780 North American cab[1]; (b) transit bus seating adjustment constraints[2].

with the steering wheel more likely. Similarly, in PATH testing of heavy vehicle automation, finding a place for an emergency kill switch where it was easily accessible, but not likely to be accidentally activated, was often difficult when considering both larger drivers and the full range of driver motions and activities.

4.3. Truck platooning

Truck platooning for increased fuel efficiency is a heavy vehicle use case that probably will probably differ from the corresponding passenger car use case. While there are advantages in terms of traffic flow and driver comfort when passenger cars are driving closer together using automation such as Cooperative Adaptive Cruise Control (CACC) [25, 34], it is unlikely that passenger car drivers will actively seek out platoons at low market penetration. However, since the business case for trucks is more compelling, some form of coordination beyond *ad hoc*, either local or global coordination, will be required to help form platoons [35]. Truck platooning adds not only new driver-vehicle interface requirements, but also requires consideration about the operations of the platoonand its impact on the surrounding traffic. How many trucks should be allowed in a platoon? How will platoons affect the traffic, vehicle movements, and the comfort levels of the drivers around them? What lane should the platoon use? How should new trucks join a platoon?

Within a platoon, there's still a question of the acceptable following distance. In a PATH on-the-road study of passenger car CACC [34], drivers were quite comfortable with following gaps as short as 17.5 m (0.6 s at 105 kph). In the SARTRE project, automated driving in a closely-spaced platoon was studied in a driving simulator to gauge acceptable following distances [36], finding that drivers begin to feel uncomfortable at following gaps of less than 15 m (0.5 s) and unsafe at gaps of less than 7 m (0.25 s). The Energy ITS project used a driving simulator to study driver take-over in emergency situations following at 10 m (0.35 s) and unsurprisingly found that it was nearly impossible for a driver to effectively intervene with manual braking to avoid a crash [37]. Unfortunately, the energy savings testing in the SARTRE project yielded that the optimal fuel savings occurred when the trucks were following at spacing in the 6 to 8 m range [28], right where the drivers felt that the following became unsafe and well into the range where drivers probably can not effectively regain control of the vehicle in an emergency.

4.4. Transit bus lane assist and docking

One of the interesting lessons learned from PATH projects demonstrating transit bus lane assist and docking is that special use cases can challenge conventional design wisdom when it comes to driver-vehicle interface design and transition of control. Human factors design guidelines tend to favor a clear, driver-initiated, transition of control

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[1] Photo from http://www.volvotrucks.com/
[2] Photo by Ben Schumin/Wikimedia

into and out of automation, but in the automated docking scenario, system-initiated transfers of control were demonstrated to be equally acceptable. In the case of bus docking, since the driver is expecting the system to transition at a certain point and the driver should be concentrating on scanning the road ahead and scanning the bus stop area for passengers or obstacles, a system-initiated transition to automatic control simply removes the step of activating a switch, allowing the driver to keep both hands on the wheel in case the control transfer fails. Similarly, conventional wisdom might suggest that if the driver deactivates part of the automation, e.g., the speed control, then steering control should be deactivated as well. However, in the docking scenario, drivers might decide to manually slow the vehicle approach based on the activity at the bus stop, but still want to keep the automatic lateral control active for the docking. While the PATH field test of transit lane assist and docking ultimately used the more conventional driver-initiated transfer of control design, engineering tests and demonstrations showed that the system-initiated control transfer design also had merits.

5. Conclusions

Although we are still in the early stages of gaining practical experience with heavy vehicle automation, the past research on truck platooning and CACC, automated bus docking and lane assist, and snow removal equipment have yielded someinteresting human factorslessons. First, there are differences in the basic motivations for vehicle automation between passenger cars and heavy vehicles, and thesemotivations can lead to different automation use cases that must be considered for heavy vehicles, potentially resulting in different system designs. Second, since heavy vehicles are generally used commercially and as part of a fleet, institutional considerations may also influence design and implementation of the automation and driver interface, but operation within the context of a fleet does off opportunities for driver training that might not otherwise be possible within the general public. Finally, the special use cases for heavy vehicle automation can challenge conventional design wisdom. Given these considerations, not all designs or conclusions from passenger car automation will necessarily apply to the design of heavy vehicles.

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