Accidents with Automated Vehicles -Do self-driving cars need a better sense of self?

3 authors:

Gunnar D Jenssen
SINTEF
17 PUBLICATIONS 205 CITATIONS

Terje Moen
Norwegian Marine Technology Research Institute
5 PUBLICATIONS 81 CITATIONS

S. O. Johnsen
SINTEF and NTNU
86 PUBLICATIONS 293 CITATIONS

Accidents with Automated Vehicles
- Do self-driving cars need a better sense of self?

Gunnar Deinboll Jenssen [1*], Terje Moen [2], and Stig Ole Johnsen [3]

[1] Mobility and Economics, SINTEF, Trondheim Norway
[2] Mobility and Economics, SINTEF, Trondheim Norway
[3] Faculty of Information Technology, NTNU, Trondheim, Norway
[*] gunnar.d.jenssen@sintef.no

Abstract: This article provides a high-level overview of the development of highly automated driving systems and illustrates challenging situations and use cases, in some cases leading to fatal accidents. Accidents with automated vehicles (AV's) and Automated Guided vehicle (AGV's) may give clues to why accidents happen and what's needed to avoid similar accidents in the future. Empirical data from 13 years of human machine interaction between Automated Guided vehicle (AGV's), employees, visitors and patients in a hospital shed light on recent accidents with Tesla's autopilot. Results indicate self-driving cars need a better model, i.e. a true 3D model of their own spatial dimensions and how it fits with safe travel. Automotive sensors may not be able to predict safe travel with current performance. Results indicate there will continue to be accidents with self-driving vehicles as long as the automated vehicle does not have a better sense of self like humans do, and that there will be an ongoing risk as long as changes to software and sensors are not made to account for the discrepancy. We outline the impact of these use cases on system design, key technologies, and their technical realization for a highly automated driving system.

1. Introduction

Over the past decades major technological changes have taken place in the field of automotive technology, with the design and implementation of new Advanced Driver Support Systems (ADAS) and increasing vehicle automation and autonomy. It is expected that automated driving will (Pink et.al 2015):

- *Improve safety by reducing human driving errors*
- *Significantly contribute to the optimization of traffic flow*
- *Help to reduce fuel consumption and CO2 emissions*
- *Enhance the mobility of elderly people and unconfident drivers*

Recent accidents with automated vehicles (AV's) have moved the driverless-car industry into a new period of more cautious optimism and testing procedures. The fatal crash of an Uber Technologies Inc. test autonomous vehicle March 2018 and separate crashes involving Tesla Inc.'s driver-assistance system has shown there is a long way to go technologically, in terms of liability as well as public opinion and end user acceptance.

Autonomous-vehicle developers are generally struggling with a multitude of basic scenarios, from making unprotected left-hand turns to judging whether an idling car is double-parked. Often these developers deal with the robot's confusion by having the vehicles slow down or stop, which can then create more confusion as other drivers join the queue or grow impatient and illegally pass.

The development of these new AV systems raises crucial questions at a technical level as well as in terms of their consequences on driver activity. A major concern is about the safety that may occur in response to the introduction of self-driving vehicles in auto pilot mode or highly automated. This paper discusses experiences of longer-term use of Automated Guided vehicle (AGV) systems and the emerging data on road incidents and accident with AV's in terms of safety and perspectives on potential risk reduction.

In this technological driven world, self-driving automated vehicles (AV's) are right around the corner. Yet, to those involved he development might seem more evolutionary than revolutionary. PROMETHEUS a European Eureka program launched in 1986 was initiated by the European automotive industry as a response to the increasing competition from Japanese car industry. The goal was to develop co-pilot systems, platooning functions and ultimately autonomous self-driving vehicles. A subsequent fifth and final workshop of the European ADASE-II project held in Stuttgart, Germany on May 17-18, 2004. It dealt with the

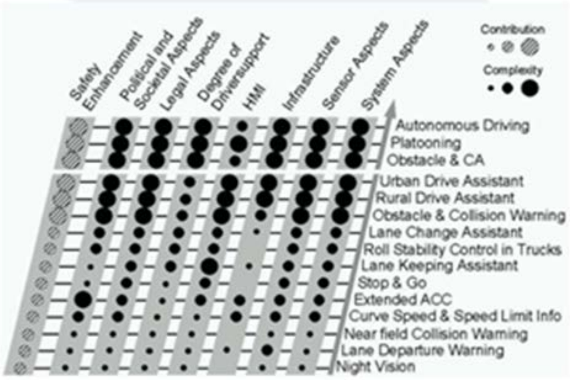

Figure 1. ADASE-II road map - development of Advanced Driver Assistance Systems and vehicle automation in Europe, related to safety enhancement, societal, legal and other aspects.

impact assessment of automated vehicle systems. The aim of the first day of the workshop was to obtain consensus about the effects of Automated vehicle systems on traffic safety, traffic efficiency and comfort. These results are integrated into the ADASE-II roadmap (Figure 1).

Based on the results, the 'white spots' in knowledge on effects were identified. The second day of the workshop focused on the Policy Framework and leads to more insight in the relation between (potential) effects of automated vehicle systems and policy issues in EU countries. With hindsight it is interesting to note the safety contribution is expected to increase with increasing automation, while the human machine interface (HMI) is expected to temporarily increase in complexity before it subsides again as full autonomous driving is introduced. Increased complexity in terms of keeping the driver in the loop. Stanton et al. (1997) also observed that some drivers with automated driver support (ACC) where late in reclaiming control of the vehicle and collided with the lead vehicle. The driver's inability to reclaim control is linked to a possible relationship between the reduced level of workload due to automation of longitudinal control induced by use of ACC.

The Organization for Economic Co-operation and Development (OECD, 1990) reflect on how driver behavior may adapt to automation and states that:

"Drivers employ the vehicle technology available to them in order to suit their driving purpose, motivation, driving style, and current physical process."

This perspective on human-machine interaction (HMI) emphasizes the need for rethinking issues concerning automation in a man-machine system. Decker & Woods (2002) elaborates on this, pointing out that automation rests on a myth by which *"function allocation by substitution"* is the prime heuristic. This approach assumes that machines or systems simply *"take over a task"*, not affecting the overall system functioning. An example of this line of reasoning is found on HMI in articles by Parasuraman (2000) defining automation as *"the full or partial replacement of a function previously carried out by the human operator"*.

The argument against such an approach is that automation does not simply absorb the given function into the system without any further consequences. "Automation does not just have quantitative consequences; it produces qualitative shifts" (Decker & Woods, 2002). Technology thus transforms and alters the practice and behavioural organization and forces the human operator to adapt the task into a new configuration. Deliberate misuse is one example of this, if the human is still in the loop.

An early article on the topic of vehicle automation in the journal Scientific American speak of the *"crashless cars"* which eventually may not need drivers at all due to a *"virtual safety bubble"* of smart sensor systems erected around the vehicle (Ashley 2008).

One of the proposed benefits of AV's are a substantial reduction of car accidents, as human errors are eliminated by automation. The American National Highway Traffic Safety administration estimate a 93% reduction of traffic deaths caused by human error (NTHSA 2015).

Yet, automation can create new types of accidents. Accidents caused by flaws in technology and the software interpreting the world around self-driving vehicles. Hence, automated vehicles are also being viewed with skepticism in their ability to improve safety. A critical issue with automated driving at this stage of its development is that it is not yet reliable and safe (Dixit, Chand & Nair 2016, Moyer 2017).

A challenge, of early systems, with partial automation of the driving task is how driving responsibility is shared and exchanged between human and machine.

Current systems that automate part of the driving task, such as Tesla's *"Autopilot,"* do not assume full responsibility for monitoring the driving environment. The human drivers are required to remain attentive and to be able to take over vehicle control at any moment should the automated systems fail. Humans may over-rely on such systems and may fail to adequately take over vehicle control, or have other difficulties using automation as observed in studies of advanced driver assistance systems (Stanton 1997, Carsten 2008, Jenssen 2010, Martens & Jenssen 2012).

One way to solve these issues are to automate all parts of the driving task and remove all possible direct human control. This is the approach favoured by Google's self-driving car project and is what the SAE International would classify as SAE level 4 or 5 automated driving systems (SAE, 2016). Ford, Uber and Volvo are also announcing they are avoiding SAE level 3 and targeting production of highly automated vehicles on SAE level 4-5 were the human is completely out of the loop.

When we automate all parts of the driving task, we often see two strategies applied. 1) the human perception-decision-action cycle is mimicked and/or 2) parts of human interaction with the vehicle and/or vehicle surroundings is mechanized and controlled by computers. E.g. as in automatic gear shift, braking and speed control. One of these computerizations of human abilities which so far has not received much attention is the concept of space in terms of representation of body space (sense of self) or the representation of self in relation to stationary and moving objects in the external world.

2. Sense of self: The neuropsychological nature of space in humans

The nature of space has many interpretations that are by no means equivalent. When we use the term *"Sense of self"* it may refer to a) the emotional component of our self-consciousness or it may refer to b) our concept of space formed and processed in the brain from somatosensory, proprioceptive and visual input.

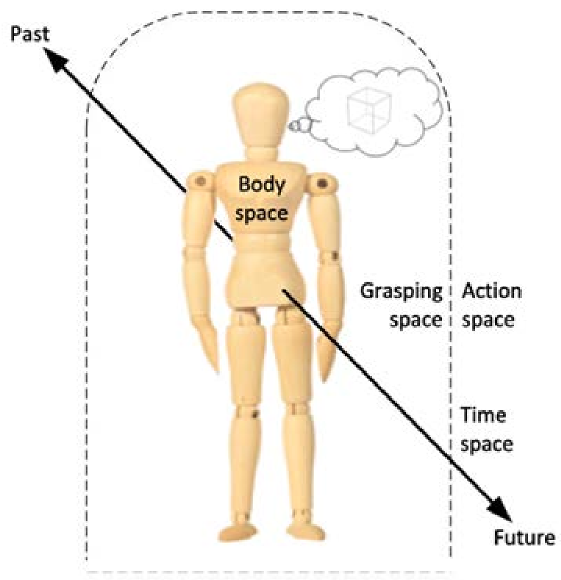

Figure 1. Human spatial behaviour and sense of spatial self can be decomposed and considered as there functionally different subspaces with a distinct neural representation

It is the latter spatial sense of self we address here. Our body occupies space, it moves through space, it interacts with things in space and it can mentally rotate and manipulate representations of space. It seems thus obvious that subspaces of the physical world must have cognitive representations in the brain. For example, we can mentally draw a map of a route or imagine looking at an object from the opposite side. Cognitive representations of space are dependent on experience and change with experience. Other objects also occupy space and maintain relations in space with one another and with us (O'Keefe. And Nadel 1978). Our spatial behaviour and sense of spatial self can be decomposed and considered as there functionally different subspaces (Fig 2), each of which may have a distinct neural representation. First there is the body surface, on which stimuli can be localized to a place. In humans, an inability to localize points on the body or neglect of the body would represent a disorder of body space.

Second there is a space immediately around the individual, which is termed *"grasping space"*. It is the space immediately around the individual in which objects can be touched directly or, or indirectly using tools. Unlike body space, grasping space is external to the body. Behaviours related to grasping are movements directed towards points immediately around the individual. Common disorders of grasping space are e.g. finger agnosia or contralateral neglect i.e. agnosia is the inability to process sensory information (to make sense of the input). It can be a loss of ability to recognize objects, persons, sounds, shapes, or smells while the specific sense is not defective nor is there any significant memory loss. Neglect is, to pay no attention or disregard information. For example, disregard a part of your body as belonging to you.

Beyond grasping space is a region that can be called action space. Several different strategies may be necessary for operation in this space. For example, within action space stationary objects maintain an absolute relation to one another but the relation of inactive objects to active moving object is relative to our position. Time and predictive timing of oneself in relation to stationary and moving object are an important part of action space. Time is obviously cognitive, we do not actually observe it, but the concept of time is conceptually different from a mental map of places although places can exist within different dimensions of time. Little is known about the representation of time, but we do know that people with frontal lobe brain damage disregard time or have difficulty in temporally organizing their behaviour.

The important point about cognitive representations of space in humans is that each of our subspaces can be represented cognitively Thus we can have a mental image of body parts, even when they are absent as in phantom limbs and of things and places in space, whether they are visible or not. For example, we can estimate the need to bend down when entering a low door based on knowledge about own body space (height, width etc.) and visual perception of the door we are about to enter. The interesting issue here is:

1. Whether automated vehicles need a cybernetic spatial representation of a form of cognitive space (body, grasping and action space) in order to move safely through traffic, and if so,
2. Whether representations of body space (vehicle body), grasping space (immediate vehicle surround) or action space (external road traffic environment is represented in current software of self-driving vehicles?

3. Definitions and terminology

In media the terms driverless vehicle, robotic vehicle, self-driving car (SDC) autonomous driving and automated vehicle (AV) is used to described highly automated vehicles. The term driverless vehicle should be used with care as parked vehicles who roll of on their own also often are called driverless by media. The terms autonomous and automated has been used interchangeably in some papers. In this paper, we have made a distinction between the two concepts. By automated we mean a system that is quite deterministic in that it will do exactly what it is programmed to do. By autonomy we mean a system that is more non-deterministic in that it has a freedom to make choices, and by automated we mean a system that is more deterministic in that it will do exactly what it is programmed to do based on input from its own sensors and systems. This description is based on the taxonomy discussion of autonomy from Vagia et al. (2016).

Yet, taking the discussion a step further an automated system can be:

1. Remote controlled – Surveilled and/or externally controlled
2. Autonomous – Based only on own sensors and systems
3. Cooperative and connected– Based on own sensors and other road traffic information (V2X)
4. A combination of 1-3

According to this line of reasoning autonomous systems are a subset of automated systems.

To explore the main risks of automated vehicle systems, a definition of the level of automation related to task execution between man and machine is useful. The levels of automation (LOA) are described by discrete steps going from no automation where the humans are fully in control to a fully automated system with no human interaction. In Sheridan and Verplank (1978) they introduced 10 steps of automation, that has been widely cited going from level of autonomy LOA1: Fully Manual Control to LOA10: Fully Autonomous Control. The LOA has been adapted to the car industry by the Society of Automotive Engineers (SAE), describing six levels of autonomy in driving, SAE (2016). Going from no autonomy (level 0), through driver assistance, partial automation, conditional automation, high automation, to full automation (level 5).

3.2 Methodology and approach

We have based this paper on empirical data from a use of automated road and industrial transport systems, a targeted literature review of automation and autonomy and safety in addition to discussion of suggested regulation of automated road transport in Norway.

We have explored experiences of automated transport systems from St. Olav's Hospital in Norway, where automated systems have been in use from 2006 to 2017.

In addition, we have performed a limited literature review based on a keyword search of automation, autonomy, safety, using SCOPUS, ACM Digital Library, IEEE Explore, Springer Link and Science Direct.

We have been involved in a hearing of regulation related to testing of automated self-driving vehicles in Norway (i.e. law on testing of autonomous vehicles), Ministry of Transport and Communications - MTC (2016). The suggested regulation was distributed in December 2016, comments to be given within March 2017 and the regulation was approved as law in December 2017. The comments were based on our literature review, experiences from St. Olav's and the other remarks published during the discussion of regulation.

The taxonomy used to register incidents has been based on Blanco et al. (2016). They collected a broad set of naturalistic accident data from autonomous driving, using a taxonomy of crash seriousness going from most serious at Level-1 to negligent at Level-4, described in the following:

C1: Crashes with airbag deployment, injury (needing doctor visit), rollover, more damage than $1,500, require towing, police reportable.

C2: Minimum of $1,500 worth of damage, crashes such as large animal strikes and sign strikes.

C3: Crashes involving physical conflict with another object, but with minimal damage. Includes most road departures, small animal strikes, all curb and tire strikes potentially in conflict with oncoming traffic and with higher risk potential if no curb.

C4: Tire strike only with little or no risk element (e.g., clipping a curb during a tight turn), considered to be of such minimal risk that most drivers would not consider these incidents to be crashes.

4. Review of accidents

Vehicle automation can enhance safety, but it can also introduce new risk in the interfaces between the autonomous system and humans, if the human is in the loop.

This is the case with SAE automation level 2 and 3. As far as we know from media and public accident reports there has been 4 fatal accidents worldwide (C1 Level). Three with semi-automated (SAE level 2) autopilot and one with a more fully automated vehicle on public roads (SAE level 3). This is the Uber accident in Arizona where a Volvo refitted with Uber self-driving technology killed a pedestrian (2018.03.18) In all cases the autopilot was engaged, but without driver interaction or intervention with vehicle controls.

Uber accidents (SAE level 3).

Date	Coun-try	No. Fatalities	System produce	Vehi-cle	Accident
18.03 2018	USA	1	Uber	Volvo Refitted	Pedestrian Fatality

Tesla Autopilot accidents (SAE level 2)

Date	Country	No. Fatali-ties	System produce	Vehi-cle	Accident
20.01. 2016	China	1	Tesla autopilot	Model S	Driver fatality
07.05 2016	USA	1	Tesla autopilot	Model S	Driver fatality
23.03 2018	USA	1	Tesla autopilot	Model X	Driver fatality

Tesla with their Autopilot has enabled automated driving at high speeds. Occasional reports of misuse of Tesla Autopilot has been reported e.g a crash with a fire truck on a Highway in California, were the driver had put the car on autopilot because he was to quite drunk. And one incident of reported suspicious riving where the police when catching up alongside the vehicle saw the driver head down was almost asleep, still having some sort of gripo on the steering wheel as required for the autopilot to function. The driver admitted engaging the autopilot because he was so tired.

Several serious accidents with Tesla autopilot have led Tesla to alter and limit their autopilot functionality. These partially automated vehicle systems on SAE Level 2 (SAE 2016), with temporary longitudinal and lateral assistance, are currently offered for series-production vehicles, but exclusively based on an attentive driver being able to control the vehicle. For fully automated driving (SAE Level 4-5), the driver is no longer available as a backup for the technical limits and failures. Replacing human, action and responsibility, with programmed machines raises questions of technical ethical and legal risks, as well as challenges for product safety.

Google car accidents (SAE level 4)

There are scarce safety data on SAE level 4 so far. As of June 27, 2019, the California DMV has received 167 Autonomous Vehicle Collision Reports. Google-Waymo has most mileage recorded and is thus of more interest than other company reports (DMV 2019). There are far more disengagement reports than accidents. Detection and disengagement issues analysed, indicate that the AV technology suffers from the same "deficit" human drivers have in its limitation for detecting and reacting to rear-end type of collisions (Favaro 2018).

Data from the period 2009 to end of 2015 collected from Googles-Waymo cars, in Teoh et al. (2017) shows there were three police reportable accidents in California while driving 2,208,199 km, giving an accident rate of 1,36 police reportable incident pr. million km. This is 1/3 of reportable accidents of human-driven passenger vehicles in the same area.

Tests with autonomous cars conducted in California by Google-Waymo have shown that 19 out of 21 accidents that the autonomous cars were involved in, were caused by expectation violations done by humans (Jenssen, 2017, Teo & Kidd 2017, Favaro et al 2017). These 19 rear-end accidents all occurred at signalized intersections, where the driver in the manually driven car behind expected the google vehicle to proceed on yellow light, but where the google car was programmed to stop. To solve this problem Google-Waymo has taken patent on the *dilemma zone*, estimating own speed, distance to stop line distance, length of the junction and time to pass, thus estimating if it is possible to pass the stop line on yellow light without violating rules of the road. Google's self- driving car (SDC) is more like a driving model of a woman than a man. Especially a young man.

A study of rear-end accidents shows that women are overrepresented among drivers in the first vehicle. They drive more *"by the book"*. They are often hit by young male drivers who drive more aggressively and expect the car ahead not to stop, even though they should according to traffic law (Bjørnskau 1993).

Making the SDC connected by car to car communication (C2C) and car to infrastructure C2I communication could make the SDC more predictive and other drivers more predictive when they know they have an SDC ahead.

Negotiating a four-way junction could also be easier in a fully automated transport system if a slot system similar to what we find in aviation decides priority addressed to the present vehicles by C2C or C2I communication.

Google-Waymo is working on several such dilemma zones "*smoothing out*" the relationship between the car's software and humans. For instance, at four-way stops, the program lets the car inch forward, as the rest of us might, asserting its turn while looking for signs that it is being allowed to go. The way humans often deal with these situations is that they make eye contact. On the fly, they make agreements about who has the right of way

5. Incidents and Accidents with AGV's

In the following section, we have documented experiences from autonomous systems at St. Olav Hospital; some selected findings of relevance from our limited literature review; and key issues discussed during regulation of testing of autonomous transport systems.

St. Olav Hospital has installed an automated transport system called TranscCar LTC2 Automated Guided Vehicle System (AGV) from Swisslog. They installed 7 AGVs in 2006, and installed additional 14 AGVs at the end of 2009. From 2010 to present (end 2017) they have had 21 AGVs in production. Each week the 21 AGVs transport medicine, food, clothes and, garbage - a total of 70-80 tons. (Each AGV is transporting 3,6 tons each week). The speed is slow, moving at approximately 2 km/hour. The maximum speed is approx. 5 km/h. The AGVs can send signals and open doors, and they can reserve elevators to deliver goods to different areas. There are different suppliers of door and elevator automation, changing of software has led to irregularities of operation. When there are conflicts that cannot be resolved, a signal is given to the operational centre, where there is human operator that can intervene, or go to the place where there is a conflict.

There are traces in on the floor indicating that the AGVs are always following the same pathway, thus common failures may happen.

There has been a total of 100-130 minor incidents (i.e. categorized as C4 by us) in one year. Minor repairs are being done on the AGVs, total changing around 50 components in a year. There are around 15 emergency stops in total each year, categorized as C3, where components must be changed. We do not have data indicating that there has been any incidents of category C2 or C1. Re-ported incidents are minor crashes due to faulty navigation, objects placed in the route travelled that is not detected. The AGVs can communicate (i.e. speak/deliver pre-programmed messages) with the surrounding human users – such as "Please move – you are in my way", or "Elevator is re-served – please move out of elevator". A critical is-sue related to the awareness building between au-tomated transport systems and humans are the above-mentioned communication from the AVGAGVs, supporting the understanding that the automated system need to inform about their perception of the surroundings and what

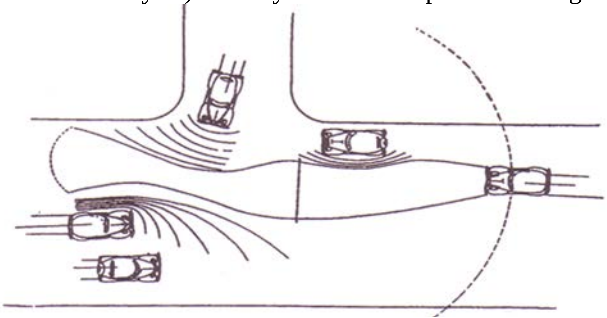

Figure 2. *Illustration of "Field of safe travel and minimum stopping distance for a driver in traffic" from A Theoretical Field-Analysis of Automobile-Driving Gibson & Crooks (1938).*

they are going to do next. In the Transcar LTC2 Operations and Maintenance manual it is written "Always maintain 1.5 meters (approximately 5 feet) between the vehicles and people or objects. This safety guideline is not possible to implement in practice at St Olavs Hospital because of space limitations.

When interviewing the users some general incidents that can be generalized were reported. First of all the AGV collided several times with the forklifts, since the LiDAR sensor had a limited vertical field of view and was seeing a free zone (space) under the forklift. This was mitigated by placing a black rubber skirt under the forklift. The same kind of collisions happened when using stepladders on the floor in the AGVs pathway being used by the AVGs. The AVG collided, since the LiDAR it did not detect the object. The AGVs also have problems with pallets close to the walls. The AGV uses the wall as reference in steering. A misplaced pallet results in a lateral shift of the AGV position and may sometime end up with a collision with the pallets. Initially the operators used a great deal of time to clear the transport road area (in the basement) from clutter (i.e. parked bicycles, pallets with supplies); this work has been reduced now. Thus, one issue has been the ability to see and identify objects in relation to the AGVs sense of its own size and position. This may be a challenge with autonomous cars – such as the death accident with Joshua Brown in a Tesla with autopilot as described by NTSB (2018) and NHTSA (2017).

Secondly, the AGVs can reserve and use elevators. Sometimes there has been conflicts between the AGVs and the users, leading to the need for human intervention through a central control room.

Finally, during the 11 years' operating the AGVs there has been no reporting of human injuries at St. Olav. However, at the AHUS hospital (AHUS, 2009), where they have installed the same system – one incident happened in 2009, where a nurse sustained a minor injury when colliding with the AGV (i.e. category C3).

In summary, the AGV system has had an impressive safety record at St. Olav's Hospital. Key issues of safe operations are related to good preparation, low speed, human intervention when needed and communication between automated systems and humans to inform about the perception from automation. The unexpected may happen, thus there is a need to establish some sort of traffic control centres manned with people that can resolve challenges with autonomous transport systems and intervene. This is partly what Google-Waymo is doing when they introduce a call centre for the pilot trials with robotaxis in Arizona.

In sum the scarce accident data so far, indicates safety hazards with automation related to both human factors and technical constraints i.e. obstacle detection (sensors), programming (rule-based), prolonged attention (human in the loop), HMI (Autopilot-engagement rules), and misuse (DUI & drowsy driver). The list may become longer as more solid safety data is revealed and more in-depth information on accident causality of automated vehicles are established e.g. interaction with personality, trust, overreliance, expectation mismatch etc. With fully automated vehicles (SAE level 4-5) issues and risk will be of a more technical nature.

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6. Sensor technology

It is quite easy to find data on vehicle sensors horizontal view in patents or publications for the sensor developer and/or supplier. In contrast there is very limited information on the vertical area of view and vertical resolution. For example, only recently in conjunction with the CES exhibition in Las Vegas 2019 Ouster, a leading manufacturer of high-resolution lidar sensors, announced its newest multi-beam flash lidar sensor, the OS-1-128 has a 45° vertical field of view and a 0.35° vertical angular resolution. Advanced imaging radar also launched at CES 2019 reveal no data on vertical area of view or vertical resolution.

7. Human Development of skills versus compared to automated vehicles

When we drive, we face constantly changing conditions to which we must adapt. This is elegantly demonstrated in the early works of Gibson and Crooks (1938). In their theory of automobile driving, important aspects of motion planning are outlined.

According to Gibson (1938), driving is predominantly a perceptual task. And by learning this perceptual process, drivers develop a mental model for the area of safe travel. This implies the driver has a certain lateral and longitudinal distance he can safely manoeuvre the car. The problem is to judge the size of this field and to progress down the centre of it. The objects in this field have valences, positive or negative, a green light being an example of the former, a red light of the latter. Deceleration or stopping is called for when there are obstacles which reduce the size of the field of safe travel. The factors which limit the size of this field are natural (ditches), inflexibility at high speeds, obstacles and their "clearance" lines, moving obstacles, potential obstacles (barriers to sight which may conceal obstacles), and legal constraints.

Besides the field of driving, two other fields are considered: the field of the other driver and the field of the car. The field of the car includes kinaesthetic and tactual cues brought to the driver through the car itself, e.g. the "feeling" that the road is slippery. The area of safe travel is determined by the minimum stop distance the driver has available to break the vehicle and avoid a collision. If the area of free movement is not large enough in relation to stop distance there is a situation of lost control. The driver is, at that moment, dependent on others to save him/her from an accident.

Many further developments of Gibson & Crook's model can be traced e.g. the threat avoidance model of Fuller (1984), which sees the driving process as one of conditioned learning. We also find traces in Hancock's discussion of engineering models of car following. He argues collision avoidance systems should be seen as an envelope of protection based upon an architecture that replicates the human behavioural response to threat (fuzzy logics), instead of a single perceptual parameter in a mathematical model (Hancock, 1993; Hancock, 2000). Schlesinger (1967) not only points out the abundance of change the driver is challenged with e.g. roadway, vehicle control, traffic, etc., but also describes the main cognitive processes involved in driving, i.e. searching, identifying, predicting, decision making and response activation. Schlesinger (1967) describes this process:

”As changes occur in the driving environment, the driver matches these changes by manipulating his vehicle. The stimuli which govern the driver’s behaviour are changes in the ratio of field of safe travel to minimum stopping zone. And as the stimulus picture changes, the driver controls the vehicle to compensate for these changes. In this task of matching output to input in a continuous flow of action, the driver is confronted with a number of sources of change. The road that he is tracking will change direction and incline, requiring him to turn the steering wheel and change the amount of pressure on the accelerator. The driver must compensate for changes in the road topography and surface, signs and signals, intersections, other vehicles and pedestrians, physical objects and the drivers own vehicle. The task of anticipating these changes involves three stages of human functioning: searching, identifying and predicting. These stages are sequentially linked and each is a necessary but not sufficient condition for efficient performance of the next stage. The task of changing the direction of acceleration of the vehicle to compensate for these environmental changes involves decision making and execution of the response”.

An attempt to quantify driver tasks is found in a German study by Platt (1986). Table 2 gives an idea of the number of observations and decisions a driver has to make per mile, and shows how low the related accident probability is. It has therefore become obvious that a simple monocausal cause-effect relation for explanation of traffic accidents is of no help (Reichart 1993). It also shows that the reliability of the human operator in the traffic system is quite good even if you account for a *“forgiving traffic system”* i.e. all the errors not leading to an accident because other road users made an evasive action or because there was no one or nothing to crash with at that moment in time and space. Errors may likewise not lead to a severe or fatal accident because of guardrails or other physical safety measures.

Table 1. Driver-related events in traffic and their frequency. From Platt, F.N. (1986).

Decisions	20 per mile (12 per km)
Errors	1 per 2 miles (1 per 3 km)
Near collisions	1 per 5000 miles (1 per 8000 km)
Collisions	1 per 61000 miles (1 per 100 000km)
Personal injury accidents	1 per 430 000 miles (1 per 700 000 km)
Fatal accidents	1 per 16 000 000 miles (1 per 26 000 000 km)

As drivers, we know the spatial outreach of our self and our car. Even though the actual top of the car or tip of the rear end is hidden from sight, we "know" where it is. Recent developments within cognitive science and neural correlates of skills, confirm that we develop not only abstract cognitive models for objects, but also develop connections on a neurological brain level representing this knowledge. Studies with functional neuroimaging have demonstrated the brain areas representing the tip of a stick but not yet the corner of a car or the skill of handling it (Povinelli, 2000; Johnson–Frey, 2004).

Autonomous cars, as currently defined, are endowed with reactive safety capabilities only, based on avoidance strategies. They have no means for *"influencing"* the behaviors of proximate vehicles that would differ from those available to human-driven vehicles. Neither do they have means to anticipate the behavior of other vehicles in all situations and make the appropriate response to that anticipations. E.g. as when the shuttle bus in Las Vegas recently was backed into by a truck. The highly automated shuttle bus was standing still and the sensors could "see" the truck backing up, but had no program for honking furiously to warn the truck driver or script to back up itself in order to avoid collision.

The next big step (fully automated driving in all conditions/scenarios) implies moving to proactive safety: rather than letting my *"neighbors"* guess what I (the SDC) intend to do (with all the ambiguities we are aware of). In a proactive system I (the SDC) will *"tell"* them, and they will *"tell"* me (the SDC), whether they agree with my intention, e.g., change lane.

Interestingly enough, if the SDC could acknowledge that a cyclist or a pedestrian is recognized as present, the self-driving car would be friendlier than a human driven car. when the systems detect and recognize people (VRU's), and stop immediately in a rule based manner. This could improve pedestrian and cyclist safety considerably. But without the negotiating right of way as human driver and VRU's do today, vehicle traffic may come to a standstill much longer than what is presently the case, seriously hampering traffic flow in urban areas.

Google's SDC is actually more similar to a driving model of a woman than a man. A study of rear-end accidents shows that women are overrepresented among drivers in the first vehicle. They drive more "by the book" (rule based).

They are often hit by young male drivers who drive more aggressively and expect the car ahead not to stop, even though they should according to traffic law.

Making the SDC connected by C2C and C2I communication could make the SDC more predictive and other drivers more predictive when they know they have a SDC ahead.

Negotiating a four way junction could also be easier if a slot system similar to what we find in aviation decides priority addressed to the present vehicles by C2C or C2I communication

8 Discussion

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Autonomous cars, as currently defined, are endowed with reactive safety capabilities only, based on avoidance strategies. They have no means for *"influencing"* the behaviours of proximate vehicles that would differ from those available to human-driven vehicles. Neither do they have means to anticipate the behaviour of other vehicles in all situations and make the appropriate response to that anticipations. E.g. as when the shuttle bus in Las Vegas recently was backed into by a truck. The highly automated shuttle bus was standing still, and the sensors could "see" the truck backing up, but had no program for honking furiously to warn the truck driver or script to back up itself in order to avoid collision.

The next big step (L5: fully automated driving in all conditions/scenarios) implies moving to proactive safety: rather than letting my *"neighbours"* guess what I (the AV) intend to do (with all the ambiguities we are aware of). In a proactive system I (the AV) will *"tell"* them, and they will *"tell"* me (the AV, whether they agree with my intention, e.g., change lane.

If the AV's could acknowledge that a cyclist or a pedestrian is recognized as present, the self-driving car would be friendlier than most human driven cars, when the systems detect and recognize people (VRU's), and stop immediately in a rule based manner. This could improve pedestrian and cyclist safety considerably. But without the negotiating right of way as human driver and VRU's do today, vehicle traffic may come to a standstill much longer than what is presently the case, seriously hampering traffic flow in urban areas.

Google-Waymo's AV behaviour is actually more similar to a driving model of a woman than a man. A study of rear-end accidents shows that women are overrepresented among drivers in the first vehicle. They drive more "by the book" (rule based). They are often hit by young male drivers who drive more aggressively and expect the car ahead not to stop, even though they should according to traffic law.

Making the AV's connected by C2C and C2I communication could make the AV's more predictive and other drivers more predictive when they know they have a AV ahead.

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9. Conclusion

Although considerable advances have been made in the last decade, towards making AV's safe, there are still critical sensor blind spots and serious flaws to sensor range, resolution and interpretation. This is evident from reported incidents and fatal accidents. Both AVG's and AV's lack a sense of self. Driving head-on into objects without any idea of their own height. Even though their sensors vertical field of view and vertical resolution may or may not have been sufficient. Automotive sensors may not be able to predict safe travel with current performance within all Operational Design Domains (ODD) as defined by SAE J3016. Results indicate there will continue to be accidents with self-driving vehicles as long as the automated vehicle does not have a better sense of self like humans do, and that there will be an ongoing risk as long as changes to software and sensors are not made to account for the discrepancy. Continuous cautious testing is required for robust implementation of the required functionalities.

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