Autonomous Cars, Trust and Safety Case for the Public

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SUMMARY & CONCLUSIONS

Today's world of road traffic is dramatically changing, triggered by the development of new technologies and a focus on accident-free driving. "Autonomous" cars are being tested several places. It is a race, among the car manufacturers, to be among the first to develop fully autonomous cars and authorities are supporting them by adapting the regulations. New technology has made it simpler to monitor the operation of cars, including their safety systems. A safety case is required by the international standard for road vehicles, ISO 26262:2018 series. UK has issued a "Code of practice" that also requires a safety case to be issued. The practice states that trialing organizations should develop an abridged public version of the safety case that should be freely available. UL (Underwriters Laboratories) a USA certification and standards development company plan to issue a new standard UL4600 in 2019 that addresses safety case for the safety of autonomous products. However, when accidents related to autonomous cars happen, minor discussions have taken place in media related to the safety evidence supplied by the car manufacturer, presented as e.g., a safety case. A safety case is normally developed to convince a third party that the product or system is safe. Our suggestion is that also a safety case for the public should be issued to ensure that (1) the public are aware that safety evidence exists, and (2) that limitations are transparent and described in an easy-to-understand way. Regulations and safety standards will provide requirements and guidelines for manufacturers, third parties and technology developers. It is, however, also important to inform the public. A safety case as it is today is too technical for the public, is often lengthy (more than 100 pages) and includes confidential information, and as a result the safety case cannot be presented to the public. A recent study, March 2019 [21], by the American Automobile Association has found that Americans remain highly skeptical to self-driving vehicles, with nearly three out of four of those surveyed saying they would be afraid to get into a driverless vehicle. We have studied the 16 existing NHTSA (National Highway Traffic Safety Administration) related self-assessment information from manufacturers. None of the reports refer to a safety case, only one report mentions safety case. Based upon these evaluations and our survey, we have suggested a public safety case with a limited number of pages, using concise, easy to read and understandable text, marks and pictures. Using such a safety case will help manufacturers, operators and early implementation sites to gain public trust.

1 INTRODUCTION

How the manufacturers and operators of autonomous cars and autonomy fleets shall inform the public is a challenge. To ensure an efficient deployment of autonomous vehicles, trust from the public is of crucial importance. Safety cases – also called assurance case or safety demonstration – have for a long time been required for safety critical systems in important industrial areas such as nuclear, automotive and railways. The earliest reference we have found is Def. 00-55:97. Safety case is an efficient method for helping the developing company to focus on the simple but important question "How do you know that your system is safe enough?" The idea of a safety case is not to provide a mathematical or statistical proof, but to argue as one would in a court of law – thus the name safety case.

Safety cases are used in an increasing number of domain specific standards – e.g., ISO 26262:2018 for automotive. Only safety experts fully understand the content of a safety case. In addition, they may include sensitive information. The idea of having a safety case for the public came up as an idea due to the importance to gain trust and to provide important information to the public. The UK Code of practice have established a similar approach delimited to an abridged public version freely available [1]. A common safety case consists often of more than 100 pages, while we expect that the public are not interested in reading more than three pages or less. We also plan to develop and evaluate internet solutions including videos, as safety evidence, that can convince the public.

2 BACKGROUND

2.1 Autonomous car and trial testing

Self-driving car development is one of the biggest trends in the automotive world today — but the companies that are working on autonomous vehicle (AV) systems can't just test their technology on any public road. Cities worldwide are increasingly the proving grounds as the pace of autonomous vehicle innovation picks up. Local governments first need to

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approve self-driving pilots to operate. The exemption is Tesla, Daimler and other companies who test beta versions of semi-automated vehicles, without need of formal permission fully self -driving vehicles are subject to. According to California law all companies must deliver annual self-reports on incidents with highly automated vehicles. This is why, Uber and many other companies decided to move test of its self-driving taxis to Arizona who has adopted a more liberal attitude.

There are two clear development trends. First, there is a race to develop fully autonomous vehicles (AVs,) i.e. self-driving cars, simply aiming to replace private cars of today with self-driving vehicles. Secondly, there is an effort to develop fully autonomous vehicles (AVs,) that will be used to provide mobility-as-a-service (MAAS) or robotaxis. The two trends are quite different in nature. The MAAS segment focus on small shuttle buses or robotaxis with geo fencing to establish a safe route. Many of these shuttle buses or robotaxis are still unable to go around an obstacle or stop until the obstacle in their pre-defined track has moved or been removed. They currently operate at low speeds between 12 -30 km/h. The aim for the private self -driving car segment is to operate more safely than human drivers in real-world conditions and at high speed, being able to handle all kinds of obstacles and interactions with other road users in all kinds of weather and traffic conditions.

There are many pilot projects with self-driving vehicles on public roads operating around the world. According to Bloomberg [2]. at least 53 cities are currently testing or considering to test AVs. Of that number, 35 cities including San Francisco, Austin, Nashville, Washington, Paris, Helsinki, and London are already piloting projects. Another 18 cities, such as Los Angeles, Tel Aviv, Buenos Aires, and Sao Paulo, are undertaking surveys or assessing the implications of AVs. Yet a quick look at the world map from Bloomberg shows that many pilot projects around the world are ignoring or not accounting for more rural pilots. E.g. only one of seven pilot projects in Norway is on the map. Legal frameworks for regulation of pilot testing is established in e.g., Singapore, The Netherlands, Norway and the UK (KMPG [3]). Furthermore, Euro NCAP has designed a set of test procedures for testing automated vehicles on SAE level 2 (NCAP [4]). The US department of transportation has developed a framework [5] for testing automated driving systems focusing on failure behavior, failure mitigation strategies and fail-safe mechanisms. Neither mention safety case as a methodology.

2.2 *Can we trust autonomous cars?*

The publics opinion about autonomous cars has received increasing interest in recent years (Hulse et al., [6]). As the car manufacturers emphasize the benefits of "driverless cars, referred to as full automation level 5 by SAE)" such as reducing the number of accidents due to human error and more efficient use of travel time, one of the key barriers to adopting this new technology is the public's trust in driverless cars (Kaur et al., [7]). The principle of "no trust – no use" has also been suggested as a guiding principle when designing automated and semi-automated technologies (Shaefer et al., [8]). There is still however a lot of unknowns in the evolving trust relationship between humans and technology. It is therefore necessary to consider some fundamental mechanisms of human psychology when new technology is presented to the public. The issue of trust is central both in terms of how to communicate the risks involved for the general public when autonomous cars are present in the road traffic system, as well as for the drivers and users of autonomous cars.

For our purpose, there are several research traditions that can give insight into the concept of human trust in automation. Trust can be defined in several ways. Trust in interpersonal relationships has been defined as "a generalized expectation related to the subjective probability an individual assign to the occurrence of some set of future events" (Rempel et al., [8]). Much of the research within human-machine interaction (HMI) has until now focused on the human operator's role in automation and when to intervene or override the automatic system. Many studies have shown that trust is something that builds up over time, and that especially for automated systems previous experience with such systems has an impact on trust development (Schaefer et al., [9]).). In driver psychology, it is known that behavioral changes occur when the road traffic system changes. These behavioral changes are expressed as "behavioral adaptation" (BA), and Martens and Jenssen ([10]). 2012) found that the amount of adaptation is (indirectly) influenced by the driver's personality and trust in the system. It is well known that a person's estimates of risk may be very different from an estimate of the "objective" or "real" risk. Whereas technologically sophisticated analysts employ risk assessments to evaluate hazards, the majority of the public rely on intuitive risk judgments, typically named risk perceptions (Slovic, [11]). When trying to convince the public, it is necessary to remember that trust is easier to destroy than to create. Slovic (1993 [12]).) described that negative (trust-destroying) events such as accidents, lies, errors etc. are more visible or noticeable than positive (trust-building) events such as safe operation. Furthermore, negative events also tend to carry much greater weight than positive events. This creates an uneven playing field when trying to present objective information about the safety of a system (e.g., a safety case).

2.3 *Safety case*

Manufacturers want to convince their customer(s) that the system is safe. At the top level, a safety case goal is simple to imagine. The statement “The system is safe because…” says it all. Whatever follows “because” is a safety case. The purpose of a safety case is to inform the reader – e.g., an assessor – about what you have done to make the system safe, how it contributes to safety and evidences that you have done what you claim to have done, including proof that the persons who did the job had the right competences. A problem with making the original safety case public is that it often contains confidential information and is not understandable for a lay person.

A safety case can be presented at several levels, e.g., expert level – a safety case designed to convince the assessor – at the medium level, designed to convince professional organizations such as the AA – Automobile Association in the USA – and the public level – “the man in the street”, who may want to buy or drive a self-driving car. In this paper, we will focus on the last of these three categories. We will, however, need all three levels since they are important for different but important groups of people – e.g., only an expert will understand the safety case required by the assessor. Since all the three levels contain different information, it is also practical to let them contain references to each-other. E.g., also, the public will be interested in what types of tests have been run and by whom. The latter is needed to create confidence. When we want to use safety cases in public space, we will face a set of challenges concerning both arguments and evidences. In order to construct a safety case for autonomous cars, we need to understand (1) what are the main public worries and (2) what would the public consider relevant evidence that the worries have been taken care of?

The most compelling evidence for the public is based on “Seeing is believing”. Thus, a public safety case could consist of the following:

- A top claim (goal) “The car is safe under all circumstance.”
- A list of worries – e.g., the car will not brake if a pedestrian is crossing the road
- For each worry, we need to define a set of scenarios and a set of videos showing how the car handles each scenario. For the break-situation this would e.g., be a set of videos where a pedestrian is crossing the road and the car breaks. This has to take place under a variety of environmental conditions such as rain, snow, fog or hailstorms.

The critical point is the selection of scenarios.We need to be aware that there is no end to the dangerous or risky scenarios that are brought into the discussion [13]. However, as long as there is trust, people will have confidence in the information provided. See also the end of section 2.2.

2.4 Relevant safety standards

Safety standards are important because they say what should be done to claim that we have achieved a certain goal – in our case a certain level of automotive safety. For automotive, the ISO 26262:2018, ISO/PAS 21448:2019, ISO 21448 SOTIF (Safety Of The Intended Functionality) and draft UL4600:2019 will have some value, also in the public domain. For the public, the important part is the safety requirements based on accident severity, exposure and controllability that is strongly related to the autonomy level. The challenge comes from the fact that all these factors are decided based on qualitative descriptions and controlled experiments have shown that qualitative assessments vary widely both for experts and lay-persons – see [14]. However, the ISO 26262:2018 safety standard is a good starting point for discussing automotive safety – also with lay persons. All this opens up for interesting and important discussions. For self-driving cards, the two first factors – severity and exposure – are related to the traffic, while the third factor – controllability – will create requirements for the self-driving care’s control system.

2.5 Relevant marks and symbols

There exist many marks and some of the marks are regulated, and others are described in international standards. CE mark, where CE is a French acronym, Conformité Européenne, European Conformity in English are regulated in Regulation (EC) No 765/2008 that established the legal basis for accreditation and market surveillance and consolidated the meaning of the CE marking while Decision No 768/2008/EC provides for rules governing its affixing.

The CE marking is familiar to millions of people across Europe. The CE mark means that the product in question conforms to all the relevant safety, health, environmental and other requirements outlined in harmonized EU legislation. All products in certain categories - those for which EU-wide requirements exist and provide for CE marking - must carry the CE label to be sold in the EU. These include computers, phones, toys and electrical products. There are product groups that are not required to carry the CE marking, such as automobiles, but this may change if e.g. the importance of trust requires use of the CE mark or a similar mark. One of the main reasons for using marks and pictograms is the increasing use of non-verbal presentation of information in buildings and for services used by the public. Graphical symbols are used where text messages might be a barrier to understanding and it is difficult to understand all aspects of autonomous vehicles. In the US, the UL (Underwriters Laboratory) mark, has a good reputation and products bearing the UL mark may result in strengthened trust by the public.

Figure 1: The CE mark and the UL mark

Fischhoff et al [15] answers the question: *What general practical advice can the science support?* Below are three of the top five advices presented:

1 *Provide numeric likelihoods of risks and benefits.*
2 *Provide absolute risks, not just relative risks.*
3. *Use pictographs and other visual aids when possible. Graphs make numeric information easier to understand and pictographs are the best graph for communicating both gist and verbatim knowledge.*

Little research exists related to use of marks, pictograms and trust. Further research is needed.

3 REVIEW OF SAFETY REPORTS AND ACCIDENTS

3.1 Review of NHTSA safety reports

NHTSA (National Highway Traffic Safety Administration) has issued a report "Vision for Safety 2.0" [16] that provides voluntary guidance to stakeholders regarding the design, testing, and safe deployment of ADS (Automated Driving Systems). NHTSA identified 12 safety elements that ADS developers should consider when developing and testing their technologies. Some of these are also relevant for the public. The report introduced the Voluntary Safety Self-Assessment (VSSA), which is intended to demonstrate to the public that entities are considering the safety aspects of an ADS.

So far [17], there are 16 manufacturers that have published reports on the NHTSA internet page. Having studied all these reports we are not, as safety experts, convinced that the ADS are safe. E.g., none of them refer to a safety case, and only the Uber report mention safety case. Four of the 16 reports do not refer to ISO 26262 and only eight refer to ISO 21448:2019. Some of them have more focus on X miles of road testing instead of a planned combination of safety analysis, simulation, testing, and safe public road testing that have been performed to ensure an appropriate level of safety for the vehicle including each software upgrade.

We doubt that the public will read these reports as they consist of from 7 to 70 pages. In addition, they are too technical for most of the public. Only two of the reports emphasize trust as an important topic.

3.2 Review of accidents

From a technical point of view, automated vehicles are already able to take over all driving tasks in dynamic traffic. Current series-production vehicles with an optimized sensor, computer, and chassis technologies enable assistance systems with increasing performance. The development has first been automated longitudinal control, then automated lateral control of vehicles.

Tesla with their Autopilot has enabled automated driving at high speeds. 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 on the basis of an attentive driver being able to control the vehicle at all times. 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.

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 have been four fatal accidents worldwide - three with semi-automated (SAE level 2) autopilot and one with a more fully automated vehicle on public roads (SAE level 3) – 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. There are few safety data on SAE level 4 so far. Data from the period 2009 to end of 2015 collected from Googles cars, in Teoh et al. [18] 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. The few accident data that we have 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). The list may become longer as more 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.

4 MINI-SURVEY

As a starting point for our understanding of safety cases for the public related to autonomous driving, we did a survey on 29 persons involved in acquiring safety critical software in the railway domain. The questionnaire used in the survey has two parts – one used to describe the participants, e.g., age, education and working experience and one part containing four questions related to automotive safety. We wanted to find a reasonable volume for the safety cases, whether they should be mandatory or not and the level of safety requirements (ASIL). In addition, we wanted to know if the respondents thought that self-driving cares would reduce the number of road accidents.

The majority of the participants had a bachelor or master's degree and were more than 30 years of age. The majority of the participants (55%) has more than 15 years of working experience. In our opinion, this makes their answers to the questionnaire relevant for our line of research. The four questions used in the questionnaire were as follows (adapted from Norwegian):

A. What is the minimum number of pages a safety case for the public should have?
B. Should the producer of autonomous cars also produce a safety case for these cars?
C. Do you expect fewer accidents when autonomous cares are introduced into the traffic?
D. Which ASIL value do you expect most safety equipment in autonomous cares to have –
    1. ASIL C or lower. ASIL B and ASIL C corresponds to the safety level in most offshore equipment on the Norwegian continental shelf
    2. ASIL D, which corresponds to SIL 3 in the EN 5012X and the IEC 61508 series
    3. Different ASIL depending on which part of the safety system that is involved

For question B there were 29 "Yes" and no "No". for question C, there were 25 "yes" and 4 "No". Thus, the prevailing opinion is that the car makers should supply a safety case and there will be fewer accidents.

Questions A and D are summarized in Fig. 2 and 3. The most common answers are that a public safety case should be a minimum of two pages and that the safety equipment in an autonomous car should be developed according to ASIL D – that same as SIL 3 in IEC 61508 and in EN 5012X.

There are, however, several respondents (nines) with one year or less experience with development or acquisition of safety-critical systems.

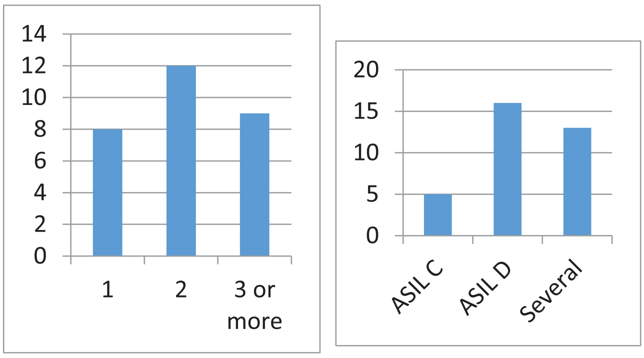

Figure 2 Number of pages(left) and relevant ASIL (right)

5 THE SAFETY CASE FOR THE PUBLIC

The purpose of the "SC for the public" is to help manufacturers of autonomous vehicles to present the operation and use of autonomous vehicles in a trustworthy manner for the man in the street. The information elements apply to the first time the vehicles are put on the market and shall be updated when there are software upgrades of one or more of the safety products or system. The "SC for the public" has to be understandable for the man in the street and easy to read. There are several rule sets for writing text that must be easy to read. This goes both for working instructions and for safety cases. There are several rules, which apply regardless of medium – see for instance [19].

Relevant information topics in the "SC for the public":

1 Manufacturer, type and version number: Manufacturer and types applies as for ordinary cars. Regarding version number, this has become more important since software can be updated during the whole lifetime of the vehicle. So far, it is normally not required to recertify the vehicle in e.g., the EU (2007/46/EC consolidated version 2019), even when safety software has been updated or upgraded. This will, however, have to change due to discovered problems related to safety and security. Changed software, even if intended as an improvement, will introduce new behaviour and thus new risks. This implies that the car, or at least the software, should be recertified. However, recertification takes time and before this has been done, the car – and thus its users – are at risk. Would it for instance be possible to release a car together with information about known vulnerabilities? The alternative – to withdraw all cars with a certain version of the software – does not look too appealing.

2 Safety, sensors and automatic systems: The automatic and autonomous vehicles must be safe. How safe is still being discussed, but why require less than for rail and aviation? This means far higher safety levels than for ordinary cars. To convince the public, the manufacturers have to inform on how this is achieved by identifying the relevant sensors, automatic systems together with relevant and understandable justifications.

3 Operational domain (OD) including weather conditions: Which public roads, geographical area, speed range and under which weather conditions are of crucial importance. In the years to come, there will be several limitations, these should be described to ensure that these aspects are fully understood by all parties, including the public.

4 Object and event detection and response (OEDR): It is important that the vehicle detects objects, including moving objects and events – e.g., accidents or an emergency unit is approaching. When these are detected, the autonomous vehicle must react in a safe manner. These aspects must be described. Important limitations must be described, but the variety of limitations are expected to decrease in the coming years.

5 Failsafe and fallback: These are two ways to ensure that the car's system has a reduced-risk state. Failsafe is the ability to enter or remain in a safe state in the event of a failure and fallback is the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding functions such as trip scheduling and selection of destinations and waypoints but including e.g. lateral vehicle motion control via steering. The vehicle must be able to notify the driver or e.g., operator (depending on the SAE level) to regain proper control of the vehicle or to return to a minimal risk condition independently.

6 HMI, SAE levels, take over and controllability: The human machine interface (HMI), is the interface between the vehicle and the driver or e.g., operator, depending on the SAE level. When introducing more automatic functions, conveying information to the driver or the operator will be more important and the information must be understandable in shorter time than e.g., the fault tolerant time interval (as defined in ISO 26262-1:2018). The controllability (according to ISO 26262, the ability to avoid a specified harm or damage through the timely reactions of the persons involved, possibly with support from external measures) of the vehicle, is important especially for the SAE levels 2 and 3.

7 Analysis, miles, V&V and Certification: The number of miles driven on the road without accidents is good information to present to the public as it is often presented by manufacturers and mentioned in newspapers. However, it is also important to inform about relevant safety analysis, simulations, testing, verifications and validations that have been performed. In addition, these tests should be evaluated and accepted by e.g., an accredited certification body. The idea of regulating accreditation is twofold. A comprehensive framework for accreditation may provide the last level of public control in the conformity assessment chain and is therefore an important element in ensuring product and system conformity. In addition, accreditation enhances the free movement of products and services across e.g. the EU by underpinning trust in their safety and compliance with other issues of public interest protection. One may then also include an accreditation mark on the safety case document.

8 Cybersecurity: Some of the current vehicles are connected to the internet. This is an increasing trend, and to be able to become a fully autonomous vehicle, the vehicle has to communicate with other vehicles and the surroundings. In addition, if the safety system is not secure, it is not safe. To ensure that security is taken care of, established best practice

and relevant standards should be followed.

9 Safety case, reference and mark: The safety case for the public should include a reference to an agile safety case or an ordinary safety case [20] that should be issued according to e.g. ISO 26262 and the corresponding safety assessment report from a certification body. Relevant marks could be presented too, but further research is needed.

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