

TNO report

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Phantom braking by AEB systems – an analysis of regulatory system verification

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Definitions and abbreviations

ABBREVIATION	DEFINITION
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AEB	Advanced Emergency Braking (as per UNECE Regulation 152)
AEBS	Advanced Emergency Braking System (as per UNECE Regulation 152)
ALKS	Automated Lane Keeping System
DSSAD	Data Storage System for Automated Driving
EDR	Event Data Recorder
FCW	Forward Collision Warning
GSR	General Safety Regulation
HIL	Hardware-in-the-loop (simulations)
ISA	Intelligent Speed Assistance (as per Regulation (EU) 2021/1958)
LKA	Lane Keeping Assist
OEM	Original Equipment Manufacturer
OBD2	On Board Diagnostics, connector port also known as EOBD
SIL	Software-in-the-loop (simulations)
TTC	Time to collision [s], measured between two vehicles
UNECE	United Nations Economic Commission for Europe
VMAD	Validation Method for Automated Driving

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1 Introduction

The Dutch institute RDW (Dienst Wegverkeer) has requested TNO to investigate the phenomena of *false braking* of vehicle advanced driver assistance systems (ADAS), commonly called ‘phantom braking’, specifically false reactions by the advanced emergency braking system (AEBS) of passenger vehicles.

The goal of this report is to document a brief study performed by TNO on the current regulations and legislation with respect to AEB systems, which focused on how these regulations add to the avoidance of *false braking* of AEB systems, in the type approval process of commercially available passenger cars. The problem currently under consideration is the small, probably insufficient, number of requirements and the quality thereof, in the legal regulations for type approval, which aim at reducing occurrences of phantom braking. Also under consideration is the cohesion between the regulations.

Part of the report are expert recommendations on potential changes, to obtain a better grip on these false reactions. The scope of this study is further detailed in section 1.2 and the problem statement is elaborated in section 1.4.

While the report has a focus on AEBS, other ADAS are also considered, because *false reactions* is a relevant topic for all longitudinal and lateral vehicle actuation, in the various levels of driving automation.

The next sections introduce AEBS, the study scope and the study’s problem statement. Then, a definition of phantom braking is given and a brief non-exhaustive list of causes.

Chapter 2 discusses the regulations that are possibly linked to, or make references to ‘false braking reaction’ of AEBS and additionally other ADAS.

In chapter 3 possible adaptations of the regulations and type approval process are discussed.

Overall recommendations and conclusions are given in chapter 4.

1.1 AEBS

AEBS can have different definitions and interpretations. This report uses the UN ECE definition. Advanced emergency braking system (AEBS) is defined by UN ECE regulation 131 for heavy vehicles as: a system which can automatically detect a potential forward collision and activate the vehicle braking system to decelerate the vehicle with the purpose of avoiding or mitigating a collision [1]. UN ECE regulation 152 is a successor of R131 and a more extensive regulation, for passenger vehicles and light goods vehicles, released since 2020 [2].

Once an impending collision is detected, such system can provide a warning to the driver. When the collision becomes imminent, it can take action autonomously without any driver input (by braking, or steering, or both). Cars with an AEB system may also be equipped with adaptive cruise control (ACC), and forward collision warning (FCW), using the same forward-looking sensors. AEB differs from forward collision warning: FCW alerts the driver with a warning, but does not by itself decelerate the vehicle.

AEB has three main characteristics:

- Autonomous: the system acts to avoid or mitigate the accident, without initiation by the driver.
- Emergency: the system will intervene only in a critical situation.
- Braking: the system tries to avoid the accident by applying the brakes.

Some 40 countries have agreed on a United Nations Regulation for Advanced Emergency Braking Systems for cars. This is expected to significantly improve road safety, especially in cities, as in the European Union alone, over 9,500 fatalities were recorded in 2016, accounting for 38% of all road deaths. Inside urban areas, 50% of the fatalities were drivers and 40% were pedestrians [3].

The UN Regulation, adopted at UNECE, lays down the technical requirements for the approval of “vehicle-to-vehicle” and “vehicle-to-pedestrian” AEBS fitted on cars. Such systems employ sensors to monitor the proximity of an object in front of the vehicle, where the object can currently be another vehicle or a pedestrian, and detect situations where the relative speed and distance between the vehicle and the object suggest that a collision is imminent. In such a situation, if the driver does not react to the system’s warning alerts, emergency braking will be automatically applied to avoid the collision or at least to mitigate its effects.

The European Union and Japan, who together led the development of the Regulation, have announced that AEB systems would become mandatory for all newly mass-production type-approved cars and light commercial vehicles (from 2022 in the EU). This would mean that over 15 million new cars in the EU (sales figures for 2017) and over 4 million new cars in Japan (sales figures for 2018) would be equipped with the AEBS technology every year.

A new General Safety Regulation (GSR) was adopted by the European Parliament in April 2019, and comes into effect in 2022. This GSR is aimed at contributing to reducing the number of traffic deaths (‘Vision Zero’) and introduces a compulsory requirement for additional systems for various types of motor vehicles. For passenger vehicles these include ISA (Intelligent Speed Assistant), AEBS (Advanced Emergency Braking System), a warning system for drivers who are at risk of falling asleep or who become distracted, reverse (driving) warning systems involving cameras or sensors, EDR (Event Data Recorder) and LKA (Lane Keeping Assist).



Figure 1: AEB car-to-car (illustration by EURO NCAP)

1.2 Scope of the study

The topic in scope of this study performed by TNO, is the synopsis of the current regulations and legislation with respect to AEB systems, focused on false reaction of AEBS, in the type approval process of commercially available vehicles.

Based on this study and own experience, TNO is requested to include recommendations for potential adaptations of the regulations or of the type approval process.

This study does not investigate the question whether, or to what quantifiable extend, phantom braking occurs and is leading to incidents on the roads in The Netherlands. It also does not include research into the possible causes of phantom braking, but TNO dedicates a brief paragraph on that topic, based on experience, see section 1.5.

Next to the focus on phantom braking of AEB systems, the report does in parts zoom out to also remark false reactions by other systems that can perform braking, and false reactions of ADAS in general. The reason is, that the existing challenges with respect to system safety verification and regulations are largely the same.

1.3 The definition of phantom braking

For accurate context of this document and the performed study, this section defines AEBS phantom braking and related terminology.

1.3.1 The definition of AEBS

According to regulation UN-R152 [2]: "*Advanced Emergency Braking System (AEBS)* means a system which can automatically detect an imminent forward collision and activate the vehicle braking system to decelerate the vehicle with the purpose of avoiding or mitigating a collision".

1.3.2 How to define a false AEBS reaction

According to section 5.1.6 of UN-R152 a *false reaction* is: "*the generation of collision warning signals and autonomous braking in situations where the driver would not recognise an impending collision*".

In this report *false automated braking reaction* is defined as: an automated braking action performed by the vehicle system (focus here is specifically on AEBS), while the braking action is not required to prevent a collision.

The way the false reaction is defined, this can mean, that the system is either:

1. Braking for no apparent reason;
2. Braking too early;
3. Braking stronger than necessary.

In case of the first point, it means that:

- There is no object in the current path, in a distance of $TTC < \text{threshold}$
- There is no object moving into the current path for the next [threshold] seconds

In case of the second point, it would mean that either:

- There is an object in the current path, but the $TTC > \text{threshold}$
- There is an object in the current path, but the current motion of the object is taking it outside of the path before $TTC > \text{threshold}$

Where TTC is the time-to-collision, which is the time that remains until a collision between two objects would occur if the collision course and speed difference are maintained. And where the *path*, is to be defined as a 3D space that the vehicle consumes, for driving its predicted trajectory for the next few seconds. The trajectory has a shape, depending on the steering input and vehicle geometry and kinematics and initial motion. The consumed space (e.g. a rectangular box around the vehicle, with additional safety margin) and the predicted trajectory are defined and computed by the system and can vary between simple and complex implementations.

It is not said that all AEBS implementations make use of TTC and *path* as in the definition above, so manufacturer's solutions could use different computations, but the above section helps to give context to the term phantom braking.

1.3.3 *The definition of phantom braking*

This report looks at occurrences of so-called phantom braking, which are false braking reactions, but not all false AEBS reactions (as defined above) are considered phantom braking.

Phantom braking excludes AEBS reactions that are only warning the driver and aren't decelerating the vehicle by braking. It also excludes AEBS braking reactions that seem to happen for an apparent reason, but too early or too strong, as categorized by point 2 and 3. "Too early" and "too strong" is driver-subjective, as it relates to the individual interpretation of danger, which makes objective assessment difficult. In this report phantom braking does include AEBS braking for no apparent reason (point 1). Simultaneously it includes false braking reactions of other functions (or systems) that can automatically brake the vehicle, such as ACC. So, phantom braking is not necessarily defined as a subset of false AEBS braking reactions. However, this report does focus on those.

1.4 **The problem statement**

To what extent phantom braking currently occurs on public roads, is unknown. In line with the *accident triangle theory*, it takes many minor occurrences for each major incident. These occurrences are typically not reported, with the exception of very specific situations, see section 1.4.2.1 and 1.4.2.2. Especially since AEB is a SAE level 1 assistance system, drivers should know that the system can misjudge, and so they might not classify such events as abnormal. Even if accidents happen due to false AEBS reactions, these might not be recorded as such, with the system noted as cause.

There are studies that link the use (and mis-use) of ADAS systems to incidents, but in general they do not include false positive reactions, rather focus on the *use* of the system by the driver and on the performance of the system in terms of dangerous (false negatives) events being missed, leading to accidents. Such studies also remark that potentially many incidents relevant to active ADAS system, are not reported or categorized as such. A good example of a recent study, which is summarizing several, is "*Who's in control?*" by the Dutch Safety Board [4].

When emergency braking engages *without* apparent reason for the driver, the occupants and also the trailing traffic can be put at risk depending on the situation. The *exposure* to the risk of a head-to-tail collision increases considerably in case of emergency braking, compared to normal driving and normal braking situations. The *severity* of such accident can be classified medium-to-high, considering that the system is required to work up to at least 60 km/h and that the deceleration are high, possibly resulting in impacts with high relative speeds. The *controllability* is medium-to-low, since the driver can override the system (e.g. by applying throttle) and since the driver of the succeeding vehicle can perform heavy braking to reduce the impact speed, but the required (reaction) time for both drivers is not always sufficient.

Due to the factor, that AEBS is designed to be able to request stronger braking than other systems, the safety risk induced by *false braking reactions* of AEBS is considerably larger than that of the same duration of e.g. ACC or ISA systems.

While this study doesn't investigate the necessity of solving a problem in terms of quantifiable risk or incidents, a simple hazard analysis (looking at *exposure*, *severity* and *controllability*) can support the strong desire of avoiding the risk of such hazardous situations as structured as possible.

Another aspect of the problem is that automated vehicles are systems for which *trust by the user*, plays a large role. Driving is a hazardous task, requiring training, and participating in traffic bears a certain trust in someone's own skills and judgement, as in that of others. When using assistance or autonomous systems to perform a part of the driving task, a person naturally compares that driving *behaviour* with their own, and by doing so increases or decreases their trust in that system. Unexplainable behaviour, like phantom braking, decreases the user's trust. Low trust can lead to drivers not using (or disabling) a system function, that is intended to increase their safety. On the other hand it can lead to drivers frequently overriding the system while the function is active, also prematurely, meaning when this is not necessary.

Related to user trust is the "customer experience", with respect to the vehicle or brand, creating an incentive at the manufacturer to limit the amount of phantom braking and false reactions in general.

The problem currently under consideration is the small, probably insufficient, number and the quality of requirements for reducing occurrences of phantom braking, in the legal regulations for type approval - and the cohesion between the regulations.

Another part of the problem of the matter of phantom braking is that AEBS developments are ongoing and systems are improving and so also phantom braking occurrences are changing over time. A quantification of the problem and the causes is therefore difficult. The regulations are analysed in chapter 2, and adaptations to the regulations, including the aspect of change-over-time, are considered in chapter 3.

The following sections zoom in on some of the aspects of the phantom braking problem and give a few recent real-world examples.

1.4.1 Other aspects of the phantom braking problem

1.4.1.1 The wide scale of braking severity

One aspect that should be noted is that phantom braking occurs on a wide scale of severity, just as justified automated braking. Especially if not only AEB phantom braking is considered, but also that of applications such as ACC. False braking reactions can be very mild, as if the vehicle detected a slightly slower object far up front – but also very severe, as if the vehicle detected a standstill object at a small distance that requires the maximum brake performance to avoid a collision.

The *level of driving automation* of the system plays a role here too. Many implementations of assistance applications are limited by design, to a certain amount of deceleration they may perform. But applications of higher driving automation levels require the vehicle system to act safely, without being dependant on the driver reaction, and can therefore not be as limited. AEBS is per definition a system operating in such a critical space, that it shares this aspect with high level driving automation systems.

1.4.1.2 The question of responsibility

The responsibility of the driving task is becoming a topic for debate in the light of automated and autonomous vehicles. Currently, commercially available systems do not surpass the SAE driving automation level 2, which by definition makes the driver responsible for the driving task, even if the driver is not having the feet on the pedals or hands on the wheel [5]. However, system applications such as AEBS do not give the driver much time, or no time at all in some cases of phantom braking, to react and override the system. In case of a false and heavy emergency braking, leading to a rear-end collision by a succeeding vehicle crashing into the falsely braking vehicle, who is to blame? Under current Dutch law, apart from a few exceptions, the driver of the following vehicle is responsible (with the main argument being accountability for keeping a safe distance) in rear-end collisions. However, depending on the specific case and situation, it could be that the driver of the braking vehicle is held responsible, by one of the exceptions in which “the driver” of the hit car suddenly braked for no apparent reason. It is also possible that both drivers are held partially responsible. Either way, the vehicle manufacturer is not held responsible. The debated question is whether this is leading towards an undesired societal scenario.

The same issue, highlighted in this AEB example, is going to become more important when commercially available vehicles start to be of a higher driving automation level, e.g. SAE level 3 or 4, in which the driver is (temporarily) not responsible for the driving tasks.

1.4.2 Recent real-world examples

The following examples illustrate the occurrence and the risk of *phantom braking* underline the problem statement. Note, that these are merely recent examples, referenced to create context. Also note that all modern vehicle manufacturers are facing the challenge of creating functionality that increases safety and comfort, and simultaneously is robust and intuitive.

1.4.2.1 Example: Westerscheldetunnel phantom braking survey and initial test

Recently, a local road authority has placed a large sign on the N62 highway in The Netherlands, before entering the Westerscheldetunnel – urging drivers to disable their ACC system while driving in the tunnel. The reason is that the operator of the tunnel has sporadically received messages from drivers, about their vehicle suddenly and unexpectedly (emergency?) braking in that tunnel. The operator claims to have performed extensive research and as a result decided that it can lead to unsafe situations and therefore placed the signs [6]. A survey was performed by the ANWB in 2019 and a follow-up initial practical analysis was conducted in the beginning of 2021 [7]. This analysis was performed with a specific vehicle model that consistently reacted falsely during every passage of the tunnel. The study concluded by recording a few different ways the system would warn the driver and would initiate braking. It also presented theories about the causes present in that tunnel, and gave some recommendations for more scientifically performed future tests aimed at finding those.

In the meantime, a similar sign was added to the entrance of the Sluiskiltunnel, also part of the N62 road.



Figure 2: “ACC OFF” sign near the entrance of the Westerscheldetunnel

It should be stated here that the warning sign is likely inadequate, since manually turning off the ACC system does not deactivate the AEB system. It is in most vehicles prominently the latter system, which can decelerate the vehicle abruptly, while ACC generally only performs light to medium braking.

1.4.2.2 Example: Recall petition for vehicle with erratic AEBS

The safety group and non-profit consumer advocacy organization Center for Auto Safety petitioned the National Highway Traffic Safety Administration (part of U.S. Department of Transportation) in March 2019 to open a safety defect investigation into false activation of Automatic Emergency Braking system of a specific vehicle model [8].

The complaints found in NHTSA's database indicated that the AEBS engaged when no obstruction was posing a threat to the path of the vehicle, according to the

Center for Auto Safety. Many complaints indicated that the braking is abrupt or forceful. Examples of environmental situations in those complaints were low overhead structures and railway crossings.

A year later, the OEM acknowledged the presence of a flaw in the system and their awareness of around 1400 reports of users. The OEM initiated a service campaign, instead of a recall, which dissatisfied the Center for Auto Safety and many users. A service campaign is effectively an optional repair, which the user is not actively made aware about, while a recall would result in all owners being provided notification of, and given the opportunity to receive the repair for this problem.

1.4.2.3 *Example: Software update leading to more phantom braking events*

During the writing of this report, an article by an automotive news website published findings on an increasing amount of consumer complaints about phantom braking by their specific vehicle model, following a software update. [9] The braking happens for no apparent reason and ranges from light to abrupt heavy braking. The earlier mentioned NHTSA has also seen a significant increase of complaints regarding the same issue.

It is noted, that users issuing complaints are generally aware that false reactions are part of the assistance functions they are using. However, functionality quality decreasing with software updates leads to lower trust of users and a higher amount of users disabling, or not using certain functionality.

This findings of this article are a good present-day example, showing the relevance of the topic phantom braking.

1.5 **The causes of phantom braking**

As mentioned in section 1.2, the causes are not analysed in this study. For the sake of context, it is however interesting to briefly mention what can be assumed at this point.

AEBS performs warning and braking, based on measurements of the ego speed/acceleration and measurements of the front object position and speed/acceleration. An algorithm computes the Time To Collision (TTC), or a similar risk value, and decision making logics act based on that value. While ego measurements are commonly very robust signals, based on e.g. wheel speed sensors, the front object measurements are more chaotic by nature. First a sensor (set) has to measure (detect) an object correctly and then those measurements have to be classified correctly as relevant front object and then the speed and acceleration and path estimations and the AEBS algorithm that decides about the risk and braking profile have to be correct.

Object detection and classification are functions that are sensitive to changes, and a lot factors play a role, due to which mis-perception and thus phantom braking are an always existing probability. From experience we can tell that generally, large variations in system braking reactions are not due to software logics or algorithms (which are comparably deterministic), but are on the side of perception, so the sensor output and the processing and classification of that. All sensors have specific properties which are ultimately limited by scientific laws and which cause fluctuations in performance with respect to object detection. With that, classification of the measured data is a sensitive matter. Other fluctuations are present in the estimation and prediction algorithms, which are getting more and more prominent.

In some modern AEB systems, several forward facing sensors are used, and their detections are fused by software algorithms. For example, camera and radar information about the same front object can be fused to create one representation of that object. In general this should lead to a higher robustness of the system. Still, when such information is not matching well or even conflicting, it has to be decided (or weighted), which is most likely correct.

Common sensor 'problems' for the implementation of algorithms such as ACC and AEBS are:

- Sensor measurements of actual objects that actually cannot cause collision because they are not in the current path, but are detected as such (e.g. overhanging signs, poles, bus stops, vegetation, tunnel walls or ceiling, steep uphill).
- Sensor signal-noise or reflections, which are not rejected by filters
 - Radar (and lidar): low signal-to-noise ratio can occur
 - Radar (and lidar): clutter can occur due to surrounding construction or natural objects such as ground, rain, birds
 - Radar: multipath echoes can occur causing 'ghost detections'
 - Camera: low standing sun, bad weather
- Sensor calibration errors, including the 3-dimensional positioning, can also be the cause of badly interpreted data.
- Sensor accuracy, especially in case of lateral motion, including lane detection and lane marker position accuracy, but also object detection accuracy
 - Radar object detection: high longitudinal accuracy, lower lateral accuracy
 - Camera object detection: high lateral accuracy, lower longitudinal accuracy

It is here that we can state, that due to the sensor limitation mentioned above, an autonomous braking system can never be 100 percent free of phantom braking. Non-occurrence cannot be guaranteed. Occurrence can, however, be decreased by continuous updating system design and system testing, by manufacturers. Therefore, for the next few years, the question will be, what amount of effort shall be required and what shall be considered reasonable?

Not only related to AEBS phantom braking, but to all kinds of false reactions in automated driving.

2 Current Regulations

EU legislation falls into two categories: regulations, which have direct and immediate force of law in all EU Member States, and directives, which must be implemented by the Member States in national legislation and regulations. The EU directives and regulations incorporate many international regulations, particularly in the field of technical requirements. These have been established by UNECE (United Nations Economic Commission for Europe) in Geneva. The main objective of UNECE is to promote European economic integration. Because the decision-making process within UNECE is aimed at reaching consensus, extensive consultation takes place at various levels.

The regulations that are considered in this study, are those with requirements for mass production of vehicles, and not those that focus merely on single or small series. Exemptions, for e.g. prototype vehicles, are also excluded.

2.1 References to false reactions in UN-R152

The United Nations Regulation No. 152 (UN-R152) defines the vehicle type approval regulations in the document titled *“Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking System (AEBS) for M1 and N1 vehicles”*. Date of entry into force is January 2020, though the regulation has later minor amendments.

The regulation scope is defined as: avoiding, or mitigating severity of impact with passenger cars and with pedestrians. Large vehicles and bicycles are not part of UN-R152, but are expected in future regulatory updates.

2.1.1 A brief summary of the document

For an AEBS to obtain type approval, three chapters of UN-R152 are key: chapter 5, chapter 6 and annex 3.

- **Chapter 5** “Specifications” lists certain system requirements that every AEBS should comply with, around 40 in number.
- **Chapter 6** “Test Procedure” lists a couple of tests to be performed, including the test conditions. Five different tests are defined, some with speed variations, totalling in 10 tests to be performed by the Technical Service (the Technical Service may decide to perform more tests by choosing more speed variations, when deemed interesting). These tests are meant to validate a subset of the requirements. All these tests are aimed at (true positive) AEB activation.
- **Annex 3** lists the required documentation that has to be provided to the Technical Service, which is system design documentation, including a safety concept to address system integrity and thereby ensure safe operation under fault and non-fault conditions. Annex 3 also states that the Technical Service performs an undefined number of nominal tests (under non-fault condition) of the presented functionality and at least one failure injection test (under fault condition) – to verify the provided system documentation. Next to that, Annex 3 adds two additional test descriptions to those of chapter 6, which are both focussed on testing for *false reactions*.

2.1.2 False reactions

When scanning the whole regulation document, a few references to *false reactions* are found throughout the document and these are all listed below.

1. In the introduction the document gives the disclaimer that the regulation cannot cover all the traffic conditions and infrastructure features in the type-approval process and that the performances required by the regulation cannot be achieved in all conditions (e.g. bad vehicle, road or weather conditions). It then makes the statement that “**Actual conditions and features in the real world should not result in false warnings or false braking to the extent that they encourage the driver to switch the system off**”. This can be considered a first requirement for the AEB system with respect to phantom braking.
2. Chapter 5 (Specifications) lists requirements for the AEB system and there is one reference under “general requirements” in section 5.1.6: “**The system shall be designed to minimise the generation of collision warning signals and to avoid advanced emergency braking in situations where the driver would not recognise an impending collision**”. The regulation requirement requires this to be demonstrated in the assessment carried out under its own Annex 3, particularly by performing vehicle tests defined in its Appendix 2.
3. Annex 3 – Appendix 2 defines two vehicle tests in which the expected result is that “**the AEBS shall not provide a collision warning and shall not initiate the emergency braking.**”. The first test is to pass through two stationary passenger vehicles and the second test is to pass a pedestrian.

2.1.3 Interpreting the references

It seems from the sections of point 2 and 3, that the demonstration for type approval is not required to be performed live at the approval authority, but can be performed and documented by the OEM as part of Annex 3 documentation, and can be ‘checked-off’ as *valid* by the authority, based on the evidence reported by the OEM.

Both defined vehicle tests of point 3 have to be performed at several constant speeds, as per UN-R152 table 5.2.1.4 and 5.2.2.4. It is not entirely clear from the regulation text, whether all of the 12 speed variants between 10 and 60 km/h must be tested, or only three of them, as is the case for the true positive tests, see section 6.6.1 (20, 30 and 60 km/h).

From the same speed tables and the test definition of point 3, it seems that even if the AEBS of a specific vehicle can operate at high speeds, or even at max vehicle speed, the UN-R152 only requires testing up to a speed of 60 km/h, as this is the speed up to which it is required to operate. This counts for both, *true positive* and *false positive* test definitions.

2.1.4 *Conclusions on the references*

There are two tests dedicated to false reaction testing (see point 3 above), both must be passed for type approval. The tests are simple, described on a half-page, with merely variations to the constant speed, no other parameters. The tests can be performed by the OEM before the type approval process and as evidence the test results must be documented and supplied with the documentation the OEM hands in at the approval authority. It is noteworthy, that the proper way of recording and documenting the test results is not defined, no method or format, nor quality or quantity is defined by UN-R152.

Furthermore, the two requirements (see point 1 and 2 above) are rather descriptive and their verification is not defined.

2.1.5 *Additional information from the informal documents*

In the creation of regulation UNECE R152, the *Informal Working Group on Advanced Emergency Braking Systems for light vehicles* held meetings from 2017 till 2021. The publicly available informal documents addressed in those meetings show that false reactions of AEBS were on the agenda a few times and several suggestions were discussed on how to perform testing against false reactions [10]. The informal documents that include references to false reactions are:

- AEBS-05-07 (J) *False reaction test proposed from Japan*
- AEBS-10-03 (J) *Study of AEBS False Reaction scenarios for passenger cars*
- AEBS-11-10 (F-UTAC) *false reaction proposal*
- AEBS-12-09 (J) *additional research of false reaction_20200514*
- AEBS-13-08 (F) *Comments to AEBS-12-11 - False reaction*

These include various test cases, defined as scenarios, with a test vehicle and a target vehicle and a target pedestrian. The scenarios include right and left turns on intersections with stationary and moving target vehicles; driving curves with guard rails, including cases with vehicles and pedestrians behind the guard rails; approaching road works with signage blocking the lane. Some of these scenarios focus on the timing aspect (whether AEB engages “too early”, as the test vehicle or the target vehicle is leaving the collision path), but most focus on the aspect of braking for no apparent reason, as defined in section 1.3.2. The documents also include a study consisting of vehicle tests with ‘normal drivers’ driving the test vehicle in these scenarios, to experimentally determine and parameterize the human behaviour of emergency braking.

It can be concluded that the Informal Working Group has attempted to create a set of test cases that would cover a lot of occurrences of phantom braking, by testing common challenges for AEB systems, such as described in section 1.5. However, none of those test cases eventually ended up in the final regulation R152 and the reasons for that are not found through the public informal documents.

2.2 References to false reactions in other regulations

2.2.1 AEBS UNECE R131

This regulation is the precursor of R152, concerning AEBS and only applies to heavy vehicles. It only includes one false reaction test, equal to the stationary-vehicles test of UNECE R152. No further references to *false reactions* are found in R131.

2.2.2 ALKS UNECE R157

The regulations on Automated Lane Keeping Systems (ALKS) is the first regulatory step for an automated driving system (as defined in ECE/TRANS/WP.29/1140) in traffic. ALKS includes the capability to decelerate the vehicle and come to a stop in order to avoid a collision, if necessary using the vehicle's full braking performance [11].

Regulation 157 does not mention *false reactions*, but instead considers 'unreasonable risk' for the driver; vehicle occupants and other road users. Via a documented Safety Concept, the OEM is required to provide a statement which affirms that the system is free from such unreasonable risks. This should include validation testing and test results, of for example simulations (SIL/HIL) or real road tests. See section 3.4.4 of the regulation. The approval authority must perform an assessment that consists of spot checks of selected hazards to establish that argumentation supporting the safety concept is understandable, logical and implemented in the different functions of the systems.

According to the *Safety management system (Process Audit)* requirement number 3.5.4 in R157, the manufacturer is obliged to perform *field monitoring* of the approved vehicle, with the aim to update the functionality and report critical incidents:

*"3.5.4. The manufacturer shall have **processes to monitor safety-relevant incidents/crashes/collisions** caused by the engaged automated lane keeping system and **a process to manage potential safety-relevant gaps post-registration** (closed loop of field monitoring) and to update the vehicles. They shall report critical incidents (e.g. collision with another road users and potential safety-relevant gaps) to the type-approval authorities when critical incidents."*

This kind of monitoring could be a way to shed light on *false reactions* such as phantom braking. When an occurrence of a false reaction leads to behaviour that is captured by this monitoring process ("safety-relevant incidents/crashes/collisions") it could, due to this requirement, then be addressed by a vehicle software update, or reported to the type-approval authorities.

2.2.3 ISA Commission Delegated Regulation (EU) 2021/1958

The Commission Delegated Regulation (EU) 2021/1958 of 23 June 2021 [12] supplements an earlier EU regulation (2019/2144) by laying down detailed rules concerning the specific test procedures and technical requirements for the type approval of motor vehicles with regard to their intelligent speed assistance (ISA) systems. The purpose of an ISA system is to inform (and sometimes assist) the

driver about the legal speed limit that is applicable to the vehicle at that point in space and time. The ISA system may rely on various input methods, such as camera observation of speed limit signage, map databases, or a combination of such inputs, also in combination with learning mechanisms such as machine learning algorithms. However, the actual presence of real-world explicit numerical speed limit signs, should always take precedence over any other in-vehicle available information. ISA as defined in [12] is an assistance system, so the underlying principle should be that the driver is always responsible for adhering to the relevant traffic rules and that the ISA system is a best-effort driver assistance system to alert the driver (this may include deceleration of the vehicle), whenever possible and appropriate. While this is currently the definition, it is worthwhile mentioning that also higher level automated vehicles will require system capabilities very similar to ISA.

The regulation mentions *false warnings* and *system updates* in these sections:

(11) In order to minimise distracting or overloading drivers with false warnings caused by sub-optimal systems in the real-world, it is necessary to ensure that vehicle manufacturers employ appropriate technologies in the vehicle fleet and that manufacturers provide, where appropriate and necessary for a reasonable proportion of the vehicle's lifetime, an unrestricted and easy access to system updates.

Requirement 5.3.4: A particular false positive detection event may be omitted from the calculations, subject to the agreement by the technical service for each individual case, where a stationary non-applicable road sign was displayed in a very realistic or life-like manner.

3.4.2.5.2.: The requirement for reliable determination of the applicable speed limit is fulfilled if the distance-based performance requirement is met in real-world driving. True positive distance ('TP_D'): the correct speed limit shall be determined for at least 90 % of the total distance and for at least 80 % of the distance driven on each of the three road types (urban roads and streets, non-urban roads, and motorways/expressways/dual carriageways) at least for applicable speed limits referred to in point 3.4.2.5.1. and where no special variable conditions referred to in point 3.4.2.3.2 apply. Compliance shall be demonstrated in accordance with a real-world driving test as specified in point 4.3.

While the requirement of point 11 is clear, it is not quantified at what point a system is "sub-optimal" and when system updates are "appropriate and necessary". Requirement 5.3.4 states that a *false warning* is acceptable if a life-like object is present to cause that, and the regulation does state in 3.4.2.5.2 that a certain amount of *false (speed limit) warnings* without any apparent reason is acceptable. For approval, the vehicle must be tested over a certain distance, driving over different types of roads that together contain a few specified different speed limits, and the test passes if *false warnings* (in terms of presented speed limits) do amount to 10% or less over the total distance. Such requirements are a good step towards acquiring some control over false reactions of assistance systems, during type approval.

While according to the regulation, an ISA system may include deceleration actuation of the vehicle by applying brakes, it does not mention false braking reactions. Requirements on false braking reactions, analogously to 3.4.2.5.2, are missing, and so phantom braking is not directly addressed.

Under "Article 4" of the regulation, the vehicle manufacturer is obliged to provide the type approval authority with statistical data over a certain time or distance travelled,

about the state of the ISA system (switched on/off, and perceived speed limits) and the occurrences of driver overrides. The latter could provide an indication of *false speed limit warnings*, if the quality of the data and the situational context information that can be extracted from it suffices to make conclusions. The regulations however, do not state what analysis should or will be performed with that data. This is not an explicit *self-monitoring process* requirement, such as the safety management system laid down in ALKS UNECE R157, which was noted above.

2.3 EU 2018/858 on approval and market surveillance

The regulation (EU) 2018/858 is an overarching regulation on the approval and market surveillance of vehicles and of systems and components in general. The regulation is not specifically defined for software functionality based systems such as ADAS, so it is written with a much broader scope, but by definition it is including such systems. Therefore there are no references to specific performance requirements of systems, nor to false reactions, but in the annexes of the document are references to several existing relevant regulations, such as discussed in the above sections, that do carry requirements.

2.3.1 Market surveillance as per regulation

The relevant addition that the regulation 2018/858 offers is the framework of market surveillance. Market surveillance should be performed, on type-approved vehicles, by a market surveillance authority in each Member State. The framework can be explained by quoting a few specific numbered points from the regulation text:

(10) This Regulation should strengthen the current framework for EU type-approval, in particular through the introduction of provisions on market surveillance. Market surveillance in the automotive sector should be introduced by specifying the obligations of the economic operators in the supply chain, the responsibilities of the enforcement authorities in the Member States, and the measures to be taken when automotive products are encountered on the market that represent serious safety or environmental risks, that undermine the protection of consumers, or that do not comply with the type-approval requirements.

(30) [...] In order to ensure the functioning of the framework, it is essential that market surveillance authorities verify compliance of the automotive products irrespective of whether their type-approval was granted before or after the date of application of this Regulation.

(31) [...] the] verification of compliance, complemented by the establishment of a minimum number of checks on vehicles per year, would also contribute to the effective Union-wide implementation of the market surveillance obligations.

The following points highlight that this framework operates at national level of the Member States, but that it is an international effort:

(33) It should be possible to use any tests carried out on any vehicle in any Member State for the purpose of taking corrective and restrictive measure in another Member State. The results of checks performed on vehicles within one Member State should be considered adequate for the purpose of invoking corrective and restrictive measures in another Member State. [...]

(44) The assessment of reported serious risk to safety and of harm to public health and the environment should be conducted at national level, but coordination at

Union level should be ensured where a reported risk or harm may extend beyond the territory of one Member State, with the objective of sharing resources and ensuring consistency regarding the corrective actions to be taken to mitigate the identified risk or harm.

Interestingly, this regulation also briefly mentions the need for frequent regulation updates and in-service (conformity) testing of vehicles that have been approved – which is in line with the arguments and suggestions in chapter 3 and 4 of this report.

(34) It is of particular importance that national authorities and the Commission consider in-service conformity testing and inspections of vehicles to be part of their compliance verification procedures. The selection of the vehicles that are to be subject to that compliance verification should be based on an appropriate risk assessment which takes account of the seriousness of the possible non-compliance; the likelihood of its occurrence; and other possible indicators, such as the introduction of vehicles with new technology installed, any past history or reports of non-compliance, the results of remote sensing testing and the concerns expressed by recognised third parties.

(37) In order to ensure a high level of vehicle functional safety, to ensure the protection of vehicle's occupants and other road users, and to ensure the protection of the environment and health, the technical requirements and environmental standards that apply to vehicles, systems, components and separate technical units should continue to be harmonised and adapted to reflect the technical and scientific progress.

(43) The continued validity of the type-approvals requires that the manufacturer inform the authority that has approved its type of vehicle of any changes to the characteristics of the type or to the safety and environmental performance requirements applicable to that type so that it can be verified that the type of vehicle continues to comply with all the applicable requirements.

Even though the regulation often refers to “technical units” and “components” the text is also applicable to vehicle systems such as AEBS and other ADAS. Article 6, 7, 8, 9 (and 10) and 13, cover the obligations of the Member States, approval authorities, surveillance authorities, the Commission, and the manufacturers respectively. The obligations related to market surveillance are encapsulated by Article 51 and 52. These two articles are part of the chapter “safeguard clauses”, and do cover:

- national evaluation of vehicles suspected of presenting a serious risk or non-compliance;
- national procedures for dealing with vehicles presenting a serious risk or non-compliance.

The first (Article 51) states that, when the market surveillance authority has “sufficient reasons” to believe that a vehicle “**presents a serious risk to the health or safety of persons** or to other aspects of the protection of public interests covered by the regulation or does not comply with the requirements laid down in the regulation”, they shall evaluate the vehicle, with respect to the relevant requirements laid down in the regulation. (As noted earlier, this overarching regulation lists many underlying regulations, such as the ones investigated in the sections above.)

The triggers to find such reasons are to be based on *“their own market surveillance activities, or based on information provided by an approval authority or a manufacturer or based on complaints”*.

The article also states that the relevant economic operators and the relevant approval authorities shall cooperate fully with the market surveillance authorities, which shall include forwarding the results of all relevant checks or tests performed.

The second (Article 52) states that after having performed the evaluation, finding that a vehicle presents a risk to the health or safety of persons (or to other aspects of the protection of public interests covered by the regulation), the **market surveillance authority shall require** *“without delay that the relevant economic operator take all appropriate corrective measures without delay to ensure that the vehicle [...], when placed on the market, registered or entered into service, no longer presents that risk”*.

It is also stated that in case of finding non-compliance, but without presenting a serious risk, the economic operator gets more time and must take corrective measures within a period that is *“proportionate to the seriousness of non-compliance”*.

Furthermore the article requires that **economic operators shall “ensure that all appropriate corrective measures are taken in respect of all concerned vehicles [...] that they have placed on the market, registered or entered into service in the Union”**.

And in case the economic operators *“do not take adequate corrective measures within the relevant period”*, the article does require the **national authorities to “take all appropriate provisional restrictive measures to prohibit or restrict the making available on the market, the registration or the entry into service of the concerned vehicles [...] on their national market, or to withdraw them from that market or to recall them”**.

2.3.2 Conclusions on market surveillance

With these rules in place, a strong framework exists through regulation (EU) 2018/858, for finding flaws in vehicle systems, including ADAS, and including *false reactions* such as AEBS phantom braking. However, in regard to false reactions, there are a few properties that weaken the framework application in practice.

How market surveillance, as per regulation (EU) 2018/858, can result in actions that decrease false reactions of vehicle systems, such as AEBS phantom braking:

- In case a vehicle system is believed to present a serious risk due to false reaction occurrences, the market surveillance authority must start an evaluation.
- In case the evaluation of the market surveillance authority concludes that false reactions indeed present a serious risk, they must force the manufacturer to decrease the risk of the false reactions, and the manufacturer must apply these corrective measures to all registered vehicles.
- After the above, in case manufacturers do not comply in decreasing the risk of the false reactions, the national authorities must withdraw them from the market.
- The framework’s existence can be an additional incentive for manufacturers to thoroughly verify vehicle systems, also with regard to false reactions, to avoid the possibility of being evaluated by market surveillance authorities, and of being forced to take reactive actions by national authorities.

How market surveillance, as per regulation (EU) 2018/858, is ineffective in decreasing false reactions of vehicle systems, such as AEBS phantom braking:

- The false reactions are to be found in practise, after type approval, by occurrences on the public road. So the feedback-loop that this framework creates, only allows for improvements after-the-fact.
- For false reaction occurrences to actually trigger the market surveillance authority to start an evaluation, they have to be reported. As already discussed, reporting of false reactions is often not done, or the data is not shared effectively (section 3.2.3), so the available reports only show the tip of the iceberg. This also means that there is a natural delay between the start of occurrences and the start of an evaluation by a market surveillance authority.
- Many types of false reactions, occurring on public road in today's implementation, will come to light not through approval authorities, manufacturers, or test institutions, but through user complaints. User complaints take time to, (a:) be collected and categorized correctly, and (b:) accumulate up to a threshold that triggers the start of an investigation. Take as example any of the cases of section 1.4.2, such as the case of the Westerscheldetunnel. These two processes take a significant amount of time, adding additional time delay.
- Furthermore, the regulation is rather indistinct: the market surveillance authority is supposed to evaluate when it has "*sufficient reasons*" to believe that a vehicle "*presents a serious risk to the health or safety of persons*". The terms *sufficient reasons* and *serious risk* are to be defined, assumingly by the market surveillance authority. With these being non-specific, the question can be raised: is AEBS phantom braking going to be evaluated, by our market surveillance authority, considering these definitions? At what specific point would that happen, so, after how many occurrences/damages/injuries/fatalities on the road, or after what kind of statements or publications by what kind of institutions?

With the market surveillance framework, regulation (EU) 2018/858 does not give a distinct tool with regards to phantom braking on the side of type approval (on which lies the focus of this study), but on the side of in-service safety monitoring. In case a national market surveillance authority of a certain Member State would conclude that adaption of specific existing vehicle system's regulations for type approval (such as UN-R152 in this study) is applicable, e.g. to reduce the risk of false reactions, it can use their connection to the Commission. The evidence needs to be built into a case for the Commission to make a proposal to amend the relevant UN regulation. The market surveillance authority could perform such requests under Article 53, item 2, point b. This states that a Member State that takes corrective or restrictive measures, shall notify the Commission and the other Member States, and can indicate whether the risk is due to shortcomings in the relevant regulatory acts. The Commission then has to act, by proposing regulation amendments, according to Article 53, item 7.

2.4 UNECE Validation Method for Automated Driving (VMAD)

Within the UNECE Working Party on Automated/Autonomous and Connected Vehicles (GRVA) [13] an informal working group has been created called: Validation Method for Automated Driving (VMAD) [14]. This working group is developing the so-called New Assessment/Test Method for Automated Driving (NATM). The concept of the NATM is shown in the figure below.

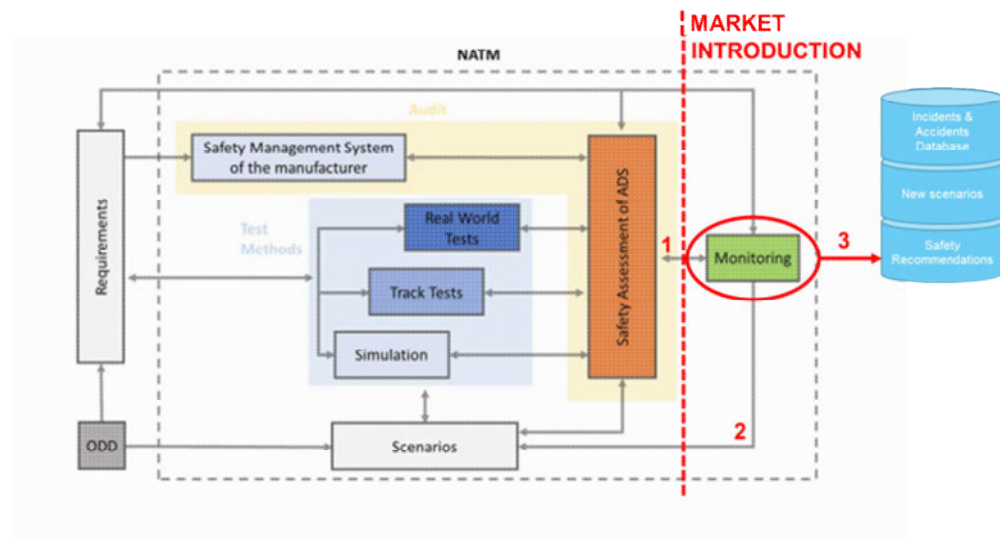


Figure 3: UNECE VMAD New Assessment/Test Method for Automated Driving (NATM)

In the NATM, 'Monitoring' has a dedicated place and is intended to serve multiple purposes:

1. Safety Assessment of the Automated Driving System (ADS) (part of NATM)
2. Scenarios: Feedback into the list of scenarios used for the Assessment of the ADS (part of NATM)
3. Used beyond NATM
 - a. Incidents and Accidents Database
 - b. New scenarios
 - c. Safety Recommendation

All of above purposes could play a role in reducing the impact of false reactions (incl. phantom braking). Where (1) Safety Assessment of ADS could look at the encountered cases of false reaction and assess the risk that is posed by them. If believed too high, an adjustment of the ADS could be required. Test scenarios to address false reactions could be updated via (2). Finally (3) could be used to get a clearer understanding of false reactions on a larger scale. This could give more insight on the extend of the different false reactions. The large set of data could be used to identify patterns, like for example area specific, or sensor suite specific issues.

The NATM as such is not finalised nor is it integrated or included in any regulation, but the elements described above have been endorsed by the WP.29 in March 2021 as a reference document. This means that, though not yet part of formal legislation, the type approval searching OEM shall have to explain deviations from the content, when it would come to court (soft law). Moreover, the validation

processes described in the document will be used by authorities for approval/surveillance. The NATM approach is promising to be able to address false reactions, but needs further detailing and implementation. A dedicated sub-group 3. *Audit & ISM* [15] within VMAD is addressing the topic of monitoring, referring to it as In-Service Monitoring (ISM). One important issue is, that the NATM is developed for ADS systems. However, many elements are also applicable for ADAS, like ACC and AEBS.

2.5 Conclusions

As mentioned above, the two AEBS vehicle tests for false reactions in UNECE R152 are very limited. On top of that, these tests can be performed by the OEM before the type approval process instead of live, and the quantity and quality and format of the evidence (including test results) is not well defined by R152.

It can be stated that the R152 test requirements related to false reactions are forceless, considering the wide variety of causes of false reactions and the fact that they are largely non-deterministic, as introduced in chapter 1. It therefore can be expected that the added value of these two tests is very limited. The main reason is, that the test situations are not challenging, but so common, that most users would deactivate the AEB system if these tests would categorially fail. To ensure a certain reasonable degree of lack of false reactions, more testing is desired. A better definition of the evidence to be supplied (quality/quantity) could help too.

Furthermore, the other two instances of requirements found in R152 (point 1 and 2), are rather descriptive. They should limit the amount of false reactions, but that depends on how the type approval checks this. There is no verification definition given by R152 on these two points, other than the two vehicle tests mentioned above (point 3).

Other regulations, referenced above, do not show a better approach at verifying the robustness of the system in terms of lack of false positive (braking) reactions, with the exception of the *field monitoring* requirement in R157 that could potentially capture specific occurrences of phantom braking. Also, the EU 2021/1958 on ISA has taken an approach of determining statistic thresholds for which the system is required to work correctly over certain driven distances with certain speed limits, essentially providing an upper limit for false reaction occurrences. However, it concerns false “speed limit determination” and does not detail requirements for false braking reactions.

Regulation R157 does apply the notion of *unreasonable risk*, which R152 does not. However, even there, *unreasonable risk* is not specified and so *false positives* and *false reactions* are not mentioned by the regulation. While it can be argued that *false reactions* can be a part of *unreasonable risk*, it takes a few steps-of-thought to arrive at false reaction testing, when designing the verification procedure to create evidence on the topic of *unreasonable risk*. Without the R157 regulations specifically mentioning and defining *false reaction*, the OEM has little to no need providing that specific evidence for R157 compliance.

Considering regulations, the OEM is however incentivized by the EU regulation 2018/858, which lays down the framework of *market surveillance*, that must be operating in each Member State. While the framework is solid for finding flaws in in-service vehicle systems (including *false reactions* such as AEBS phantom braking), due to its nature it is not effective in the same ways that type approval requirements

are. The reasons are mainly that the market surveillance framework only allows for improvements after-the-fact, so after a significant amount of riskful occurrences on public road leading to registered complaints, and that it contains a significant time delay.

Within UNECE VMAD a promising approach to address false reactions via *monitoring* is being created, but requires further detailing in order to evaluate feasibility and usefulness of addressing false reactions.

3 Possible adaption of the regulations

The current AEBS regulation R152 could be adapted in two ways, to enforce the system-producing parties to improve on the frequency and severity of *phantom braking*. Either the type approval requesting party must provide more, specific, evidence of system design and system verification – proposedly as part of Annex 3. And/or the approving party must perform more, specific vehicle tests, as part of the approval – proposedly as part of Appendix 2.

Either way, more evidence is needed to verify the robustness of the systems and in this chapter TNO proposes two paths to obtain this.

3.1 Testing

Looking at the bigger picture of automated and autonomous driving systems, it is clear that these systems are becoming more advanced at a rapid rate. Simultaneously, they are becoming more complex. It is now already nearly impossible to fully test each individual software function, that can influence the actuation behaviour of the vehicle. When zooming in further, on software function inputs, parameters and even on lines of code, we have to realize that an important principle in software testing is, that exhaustive testing is impossible. On top of that, software starts becoming non-explicit, with machine learning methods being introduced. What's left to actually test is on a higher level: *can the vehicle system safely handle all reasonably foreseeable (realistically occurring) situations with preventable safety risks?*

That can mean a number of things. One being that, given a certain situation a vehicle is in, the functionality can handle the vehicle safely (within the required bounds) because the situation is part of its operational design domain, or it can correctly determine that the current situation is not part of the domain it can handle. Another one being that when (a part of) functionality of the vehicle system would perceive or compute situational information wrongly or even fail, another part of the system would mitigate that.

In the previous two chapters it becomes clear that phantom braking is not a system fault that can be easily isolated and tested repetitively, as it is a false positive response in which the system responds when it is not required or wanted, and because its occurrence is immensely dependent on the situation and environment. Ideally, statistical empirical testing is desired to catch all kinds of (critical) situations of driving in the real world. For the current type approval process that is not possible, as it aims to be brief by performing a few key tests (sample testing), that are supposed to proof the soundness of the complete submitted design and implementation.

With that in mind, we propose two ways to reduce the impact, and increase the resilience against phantom braking, or undesired system behaviour in general, by regulation adaptations. The proposed adaptations are:

1. Implementing an **extended sample-testing** requirement in the regulations, that requires the approving party to perform a certain low number of tests, out of a list with a large amount of tests. So scenario-based testing with the possibility to

select scenarios. All those tests are specifically designed to raise false reactions, and thus do expect no braking actuation. The requesting party is required to supply the evidence of testing all of the tests on the list. Purely for numerical context: the proposed numbers could be 10 random tests, out of 100 defined tests.

2. Implementing an in-service monitoring methodology, requiring the requesting party to record on-board data under specific conditions with a certain amount of vehicles (or all vehicles). That data, or a certain result of it, is shared with the approving party, such that a statistical empirical analysis can be performed over the extend of a certain amount of time and driven kilometres on public road.

The following sections provide more information on these two methods.

3.1.1 *Extended standard sample-testing*

Phantom braking occurrences are often caused by specific sparse environmental situations in the real driving world, that are not present on an average test track. A good example are the reported occurrences in the Westerscheldetunnel (section 1.4.2.1), but also situations are known to TNO out of vehicle testing experience. An example of the latter is driving in Amsterdam on a slightly bend part of the Nassaukade, during which the vehicle faces a bus stop that can frequently lead to a false trigger of AEB, in certain tested commercially available vehicles.

As stated, it is not possible to outline a test for *all* cases, but especially with some effort on a pre-study that finds the statistically relevant occurrences, or that is based on engineering knowledge and on experience (as in above example), a number of test cases can be defined that could cover a large amount of occurrences. Without trying to state that phantom braking is a phenomenon that can be approximately described using a normal distribution, the figure below illustrates that with the right, but still non-complete set of cases, it is possible to cover a significant part of all cases.

Such an extended list of test cases would add to the current two defined test cases of UNECE R152 (see section 2.1.2) and introduce thorough 'true negative' testing, to reduce the occurrences of 'false positives', such as phantom braking.

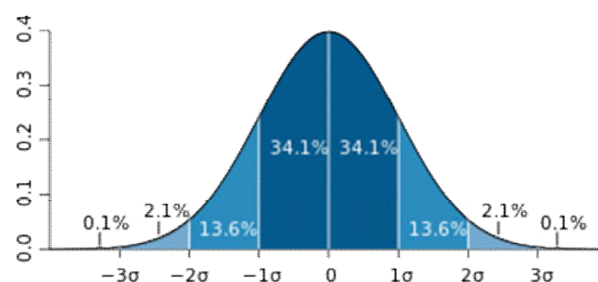


Figure 4: The normal distribution shows the possibility of covering a significant amount of cases with non-complete data (image source: wikipedia.org)

Tests should also be shaped around the system implementation of the AEB system. Depending on what parameters are used by the AEB algorithm and decision making logics, certain tests become relevant (or irrelevant). For example, a relevant question could be whether the AEBS of the tested vehicle includes the (measured) yaw rate of the vehicle. Tests should then include driving through curves at different speeds or various curvatures. When selecting a small number of tests out of a large set, for type approval at the approving authority, such system aspects should be considered.

Pro's:

- Certain occurrences of phantom braking can be covered by a limited list of tests, especially those that occur more deterministic.
- Increasing the resilience against false reactions by any percentage is better than none.

Cons:

- The method can never cover all cases.
- The defined test list requires to be updated every year, or every few years, to stay relevant, since the implemented technology changes and also the insight about relevant occurrences changes.
 - Then a question arises whether all already approved vehicles have to be re-approved.
- The method does not handle software updates of vehicles well, unless already approved, but recently updated vehicles are going to be re-approved, according to the updated regulations.



Figure 5: Bus stop on bend part of Nassaukade in Amsterdam can trigger false AEB reactions, as encountered during specific vehicle tests (image source: Google Street View)

3.1.2 *In-service monitoring*

A vehicle type approval process does not allow for the resources of extensive function/software testing. While extensive testing for evidence is not an option, and while not testing functionality at all is also not an option, current regulations however, include only a few defined test cases, which were apparently deemed of the highest relevance when the regulation was formulated. In this light, the *extended standard sample-testing* solution is proposed above.

Currently, ADAS technology is developing quickly with great advancements every year. Sensor technology and in-vehicle computing power is experiencing rapid growth and there are now several times more lines of code in passenger vehicles than in passenger airplanes [16]. OEMs are starting to update their vehicle system functionality by software updates, over-the-air (OTA), without any hardware changes or visits to their respective car dealerships. This allows for more flexibility and enables the implementation of in-service monitoring and software updates to improve encountered issues.

With a relatively rigid regulation like the UN-R152 it is becoming difficult to handle rapidly updating vehicles. Considering this challenge and the conclusions of chapter 2, in its current form the UN-R152 might not be the right framework anymore for the vehicle type approval process.

The UNECE seems to recognize this, as can be concluded from e.g. recent regulations like the UN-R156 concerning management of software updates [17] and the working group VMAD [14].

This is also relevant after obtaining type approval. Digital components and software systems do not generally suffer gradual loss of performance as a result of (mechanical) wear, but as a rule fail abruptly, without prior warning. For components like sensors, that can in a way degrade over time, it is often not visible from the outside, nor readily measurable. As a result, problems with digital components are often not discovered during a periodic inspection (MoT) and for that reason periodic inspection is not suitable for digital components. Some form of continuous monitoring would be more suitable for a “computer on wheels”, than an MoT, quoting the Dutch Safety Board [4].

To test complex, dynamic functionality thoroughly, or rather *analysing* it, requires a statistical approach including a lot of data of the vehicle system driving in real-world conditions, for many kilometres, so called field-operational-tests (FOT). This is a typical activity conducted by the car manufacturer or the TIER1 system supplier in the development phase, to prepare for deployment on the public road. Or for research purposes, sometimes externally coordinated with multiple stakeholders. Based on the results of such FOTs, it can be indicated how the vehicle behaves under the conditions that were encountered in these tests, and in which situations the vehicle system performs undesired, potentially unsafe. Typically, such tests include driving under unfavourable conditions, to challenge the system-under-development.

An implementation of such data-driven examination in type approval regulations, is *in-service monitoring*, in which the approving party is getting access to recorded data from the requesting party. This data comes from a fleet of vehicles equal to the

one under approval. The monitoring could be performed by the requesting or the approving party, the exact implementation of data-sharing is to be agreed on, but either way the approving party must frequently obtain evidence on how the vehicles are monitored and what the (statistical) results to their test cases/situations are. The idea is that (independent) specialists can accurately aggregate relevant information from the data, finding all kinds of occurrences of false reactions, determining the events that lead thereto, and determining the possible causes. Rather than relying on driver-feedback in the form of reported complaints, as in the simpler way of performing market surveillance (section 2.3).

Pro's:

- More thorough function evaluation (in this case AEBS), by the larger amount of data on correct AEB events and phantom braking events.
- Robustness testing, by the natural variations in parameters and function inputs, because test cases are not predefined.
- Assessing real-life situations, rather than isolated test environments.
- Assessing safety of in-service vehicle systems, without the need for presence of certain triggers of the market surveillance framework of 2018/858, and without the delay it naturally brings.
- Ability to continuously re-test, assessing function updates throughout the life-cycle of a vehicle. This enables finding false reactions introduced by updates of ADAS software, as well as inadequate ADAS hardware/software maintenance.
- Ability to reveal more common situations (or locations) in which phantom braking is triggered, which then could be added to sample-testing methods.
- Monitoring data may be able to be used for much more than analysis of safety critical events of a single vehicle – and certainly more than analysis of false reactions.
 - One example is, using monitoring data to analyse the safety of a certain infrastructure area (e.g. a specific intersection, highway junction, tunnel)
 - Another example is, using continuous monitoring for the addition (or replacement) of pieces of the periodic vehicle inspection (MoT).

Cons:

- Requires vehicles on the public road to enable the data-assessment, so type approval sample-testing cannot be fully substituted by in-service monitoring.
- Requires data-sharing policies (legal aspects).
- Requires data-sharing protocols (technical aspects).
- Requires OEM developments regarding data logging, storage, sharing – and monitoring.
- Requires specific calibration, testing and maintenance of the recording system.
- Requires continuous resources to perform the monitoring and data-based assessment over time.
- Requires setting up metrics and processes that allow making conclusions on monitored data and taking follow-up actions (with respect to type approvals).

As noted in chapter 2, via UNECE R157 the first steps are made to use in-service information in the safety assessment, where the initiative lies with the OEM. The list above however shows that there are a lot of topics to be addressed and work to be done, before an independent in-service monitoring method can be included in type approval regulations. The method for this is currently being defined and detailed in UNECE VMAD (section 2.4). A solution to the data-sharing aspects could be the

installation of (temporarily) additional monitoring equipment in the fleet of vehicles to be monitored. Data of in-service vehicles is challenging, as confidentiality and privacy of both OEM and driver need to be considered. A dedicated informal working group within UNECE VMAD is active to address this topic; Data Storage System for Automated Driving / Event Data Recorder (DSSAD/EDR) [18].

3.2 Other regulation adaptations

Next to extending testing as part of the type approval, other adaptations could lead to the desired result of less risk on the public road, by false AEBS reactions, or by false ADAS reactions in general.

3.2.1 *Regulating system limitations*

An example is to limit the deceleration capabilities of systems like AEBS in the regulations. Hypothetically, it could be concluded by safety analysis studies that false braking reactions are of significantly less risk for the road users when these are below a certain deceleration. In that case, requiring such limit by regulations could be sensible. On the other hand, an AEB system is designed to act at the last possible moment and thus requires a high deceleration to decrease the risk of a collision in many cases. Applying a deceleration limit is most likely adding more risk than it can reduce. Also, applying a deceleration limit could introduce more occurrences of false positives, as braking may need to start earlier.

3.2.2 *Regulating system implementations*

Another example is to require a specific implementation of the AEB system by the OEM, via regulations. For example, a system using a single radar is more prone to false detections and thus false reactions, than a system that decides based on multiple sensors. Especially when those sensors rely on different scientific principles, so for example radar plus camera. Being a very specific requirement, limiting the design freedom of OEMs, and considering the variety and quick advancements in sensor technology, it is unlikely that such requirement could be added to regulations.

3.2.3 *Regulating accidentology feedback*

An alternative, or even addition, to the adoption of *in-service monitoring* for type approval, could be a regulated feedback-loop of accidentology. By properly recording the in-vehicle system data of (near-)accidents, and dissemination of that data upon registration of the accident, a regulatory body could assess the causes and effects. Consequently, OEMs could be requested to update their system, or regulations could be adapted to cover newly gained insights.

Though, this method is not an effective alternative to in-service monitoring, because it covers the analysis of far less events, namely only those that lead to registered accidents. In-service monitoring can actually act preventive, and instead of relying on a significant number of accidents, it can avoid help them.

A challenge in using accident data is that, empirical data about accidents in which ADAS have played a role are currently often not available. A number of shortcomings with regard to the storage and collection of accident data is identified by the Dutch Safety Board [4]:

1. Data are not always stored. And if it is, it is not always possible to ascertain whether the ADAS present in a car were actually switched on.
2. Data are stored in a proprietary format. As a result, those data cannot be read out without assistance from the manufacturer.
3. Data are stored encrypted. Here, too, the data cannot be read out without the assistance of the manufacturer.
4. Data are stored distributed across various modules of different suppliers and it is not always clear where those data are stored.
5. In addition, empirical data are not available because accidents are not registered. Generally speaking, the registration level is low (approx. 30% for accidents involving serious injuries).

4 Recommendations

4.1 Type approval

4.1.1 *The current UNECE R152*

Additionally to all nominal functionality tests performed for the current R152, which verify 'true positive reactions' as per chapter 6 of R152, it could be recommended to include the verification of absence of false positive reactions. From the start of each test, leading to the to-be-defined moment where the emergency trigger arises (e.g. the range where the driver can still avoid the collision and no warning is expected), AEBS should not engage. The regulation requirements can give such definition and could state that false braking reactions (phantom braking) will lead to the test being classified as *failed*.

The two tests for false reactions in UNECE R152 are very limited and the requirements do not seem to be well defined, considering the properties of phantom braking, as concluded in section 2.5. An extension of the regulation test cases is recommended, in line with section 3.1.1 and in line with ideas of the Informal Working Group during the creation of R152 (section 2.1.5). In short, the recommendation is to:

- create a much more extensive list of various test cases that are known to trigger unjustified AEB.
- require the approval-requesting party to provide evidence for all those tests
- require the approval authority to sample-test a small number of those test cases

4.1.2 *Dynamic test suite*

TNO believes that the future test suite, with specific future tests performed by - or test evidence collected by approving parties, is preferred to be dynamic rather than static. During the life-cycle of a vehicle, technology may change significantly and the vehicle's functionality may change considerably by software updates, sometimes requiring new approval. Next to that, new insights are gathered in that time, e.g. based on research, accidentology, or user complaints, about what aspects are actually safety-critical, what situations are challenging for automated systems, and what system flaws are currently trending. Tests should be updated at a similar pace, to incorporate the changing application use cases and the new insights. This is however complex to realise and a static extended list, as suggested above, is already an improvement, for a start.

For a dynamic test suite, a shift is necessary from static test definitions as available in current regulations, towards an iteratively updated test database.

4.2 In-service monitoring

Technology is advancing fast, vehicle functionalities can change significantly by OEMs updating software over-the-air, insights into unsafe system behaviour (and the causes) change while these systems are operating on the roads. In-service monitoring is a complementary tool to the current rather static regulations to cope with that dynamic phenomenon. And so, in-service monitoring is a recommended

part of the solution to tackle false reactions, including phantom braking of AEB systems, but also in the wider context of ADAS and AD vehicle applications. In particular data-driven in-service monitoring based on analysis of recorded data gained from operating vehicles (section 0), which allows for a much faster and more directed feedback loop than the *in-service compliance framework* of market surveillance as currently executed by Member State authorities according to regulation (EU) 2018/858 (section 2.3). With the ability of in-service monitoring to continuously re-test and assess function updates throughout the life-cycle of a vehicle, *regulated in-service monitoring* can be recommended as a powerful implementation of market surveillance, by forming an input (a trigger of Article 51) to the existing safeguard clause of that regulation. This way a feedback loop would be created between monitoring and type approval tests, which, with the right implementation in regulations, can result in a dynamic test suite as suggested above.

The conclusions of the previous chapters point towards a future, with a sort of in-service monitoring, as described in section 2.4 and 0. Consequently, a discussion is required between authorities, industry and testing institutes to determine how to organize such in-service monitoring. Part of that is initiated by the UNECE VMAD working group, as described in section 2.4.

4.3 Concluding

TNO suggests to adapt (and create future) system level regulations such as UNECE R152, to specifically include a higher quantity and quality of *false reaction* tests. It is also recommended that the test suite is dynamic, i.e. adapted over time, to take in latest insights. This is the most direct way, before type approval, of preventing and finding false reaction related safety issues, albeit not complete.

Several legal mechanisms are in place via the existing UNECE, GSR and EU regulations, to address system faults, which could include false reactions. These mechanisms have their limitations and probably, in practise, an issue of indistinctiveness. The latter due to the fact that they are general regulations, rather than regulations specifically for ADAS applications. One of the biggest limitations is that they only allow for improvements after-the-fact, because they are triggered after a significant amount of riskful occurrences on public road leading to registered complaints, which contains a significant time delay.

TNO also suggests to put into place an additional in-service monitoring mechanism which gives insight into safety issues due to false reactions at a much faster rate (while covering much more than the specific type approval tests), by data analysis from operating vehicles. The information gained this way can then serve as a trigger of the existing legal mechanisms, such as market surveillance. For this to work, monitoring and analysis has to be performed for the specific cases of interest, such as *phantom braking*, and not only limited to cases that lead to accidents. Therefor a requirement stating what and how to monitor and analyse will be needed in the future, more specific than the current requirements about monitoring in e.g. UNECE R157 for ALKS. This could be done under further development and implementation of the VMAD-NATM concept.

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6 Signature

