National Technical University of Athens - Aristotle University of Thessaloniki

Workshop on

"The role of Advanced Driver Assistance Systems on traffic safety and efficiency"
Athens, October 18th, 2000

State-of-the-art on Advanced Driver Assistance Systems

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Abstract

The objective of this work is to present the state-of-the-art on a set of Advanced Driver Assistance Systems (ADAS) with high potential to contribute to the improvement of road safety, traffic efficiency and environmental conditions. This state-of-the-art gives a broad overview of ADA systems under development or in some cases already available. Twenty-seven advanced driver assistance systems are examined, classified into the three distinct phases of the accident process: pre-crash, crash and post-crash as well as into the two categories of driver support functions: tactical and operational. Of each system various aspects are being described, from functional description to market impact, and from user needs to strengths and weaknesses of ADAS, according to the availability of information for these new systems. Intelligent vehicles and roads are the future standard and specialised research should be intensified for the identification of their impact as well as their adaptation to the real user needs for safer and efficient transportation services.

Key-words: advanced driver assistance systems, road safety, traffic efficiency

1. Introduction

Today the use of Advanced Driver Assistance Systems (ADAS) presents a rapidly growing importance as these systems are expected to improve road safety, increase road capacity and attenuate the environmental impacts of traffic. The advent of new technologies makes the use of these advanced driver assistance systems less unapproachable to the wide public, allowing for safer and more efficient driver experiences.

From safety point of view, advanced driver assistance systems may enhance the perception of the traffic environment and so enhance situation awareness in the driver, may assist specific manoeuvres like overtake checker or obstacle/pedestrian detection, may avoid impending collisions (rear-end or intersection collision avoidance) and may adjust the maximum speed to traffic and roadway conditions.

These systems may satisfy important needs the driver has when carrying out the driving task on manoeuvre and operational level. Systems that are made to increase driver comfort such as advanced cruise control and navigation systems may have little or indirect effect on safety, but navigation systems are expected to reduce environmental load and congestion somewhat due to a reduction in superfluous driving. The potential benefits to traffic capacity from the wide-spread use of ADAS [limiting the use of private transportation, stimulating (combined) use of public transportation, homogenising traffic flow, etc.] may provide solutions less costly and often more feasible than the infrastructure related solutions. Moreover, these systems may have the potential to co-operate with infrastructure-bound traffic management systems.

The objective of this work is to present the state-of-the-art on a set of Advanced Driver Assistance Systems with high potential to contribute to the improvement of road safety, traffic efficiency and environmental conditions. This state-of-the-art gives a broad overview of ADA systems under development or in some cases already available.

Within this state-of-the-art a comprehensive list of ADAS is proposed, nevertheless the reader should be aware that many of this ADAS could be combined to create more sophisticated functions. A good example is given by the IVHS/platooning systems, which integrates both lateral, and longitudinal control of the vehicle. Indeed the combination possibilities are very large. It is envisaged that in the near future ADA systems - until now mostly separate systems - will be integrated into one overall system.

The appropriateness of the various ADAS for enhancing safety, decreasing environmental impact and increasing road capacity has been used as a basic dimension for the classification of the presented systems. In terms of safety enhancement, the classification is based on the three distinct phases of the accident process, in particular: pre-crash: phase preceding the crash, crash: the crash itself and post-crash: phase after the crash. Furthermore, the systems that offer a broader scope of driver support are presented in two separate categories covering tactical support functions and operational level functions. (Heijer et al, 2000)

2. Pre-crash related functions

2.1. Navigation based function

Enhanced navigation, navigation routing

This feature will provide location and route guidance input to the driver and will support the various collision avoidance capabilities with road geometry and location data. It will also provide the necessary capability to filter traffic information RDS-TMC (Radio Data System – Traffic Message Channel) to select those messages that are applicable to the vehicle location and route of travel. It will also offer the capability to recommend optimal routing based on driver preferences. More advanced versions of this service may integrate real-time traffic conditions into the calculations of optimal routes. An extra module will enable the receipt of information sent via GSM. The navigation display can also be used helping the driver when parking, using a camera viewing backwards.

Integrated navigation

This feature will provide to the driver intelligent in-vehicle information, signing, warning, and/or automatic action when:

- advising the desired route
- reaching the speed limit
- approaching a location with a low safe speed, such as a sharp bend or intersection
- safe headway is jeopardised
- imminent risk for a collision arises.

This will also include information about environmental and road surface conditions to provide the driver with warnings such as excessive speed for curves (perceptual judgement of speed) or alerts on upcoming traffic signs and signalised intersections (reaction time and merging difficulties in junctions). This feature may include the ability, at unusually complex and hazardous highway locations, to replicate one or more types of highway signs on a display within the vehicle.

These capabilities will result from extensive integration of in-vehicle navigation and route guidance features with intelligent speed adaptation ISA, advanced cruise control ACC, collision avoidance system, pertinent vehicle dynamics and position of the vehicle towards other vehicles, environmental information with knowledge of road geometry (from map database or beacon input) and vehicle position (DGPS) and automatic SOS when crashing. (Hayward et al, 2000)

Real time traffic and traveller information – distributed navigation

These IVI systems will have capabilities to access in-vehicle databases and receive travel-related information from the infrastructure (roadside or wide-area transmissions). Information categories will include items such as vehicle location and route guidance instructions, motorist and traveller services information, safety and advisory information, and other real-time updates on conditions such as congestion, work zones, environmental, and road surface conditions. This feature will provide an integrated approach to the presentation of information to the driver for safety warnings and other advisories related to the driving task. More advanced system capabilities will include the ability to react to dynamic information on environmental and road condition thereby augmenting information contained in the static map databases. Dispatching services for fleet operators are included in this category.

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2.2. Man Machine communication

Automated transactions – electronic toll collection

This feature would implement capabilities for non-stop (high speed) electronic transactions, such as electronic toll collection, parking fee payment, and additional commercial vehicle-related functions, such as credentials and permit verification, using such technology as transponders and "smart cards". Tolling can be conducted on motorways only or on all kinds of road in an area, during rush hours only or permanently, for all vehicles or e.g. only for heavy goods vehicles, discrete or continuous (tax per kilometre driven depending on time and place, vehicle type). Automatic or also manual collection, e.g. for foreign non-equipped vehicles. Enforcement will also be conducted automatically using video pattern recognition techniques.

All systems use the smart card, mostly ‘contactless’. Different techniques can be used such as DSRC technology, i.e. dedicated short range communication, chosen by most European countries, linking road-side equipment and on-board units. Pre-standards have been formulated by CEN for DSRC (CEN, 2000). Based on these pre-standards there is a need for harmony, i.e. interoperability of different systems and cross border use. A different electronic fee collection uses a combination of satellite location (no implementation of costly large-scale road side equipment needed) and mobile communications. Equipment needs then to be able to operate in both modes, i.e. GPS/GSM and DSRC. The electronic number plate will facilitate electronic tolling. Harmonisation of classification of vehicles and of legislation on enforcement of offences is a must, so evidence of proof accepted in one country is automatically valid in the others. (Hamet, 1999)

2.3. Driver monitoring

Driver vigilance monitoring

This feature would provide a driver monitoring and warning capability to alert the vehicle or the truck or bus driver to problems such as drowsiness, or other types of impairments. The term “ driver impairment ” encompasses all the situations in which the driver’s alertness is diminished, and therefore when the driving task cannot be maintained at an adequate level of performance. It is a consequence of stress, fatigue, alcohol abuse, medication, inattention, effects of various diseases. (Grace, 1999; Boverie et al., 2000)

Driver health monitoring

As *healthcare* becomes an ever-larger segment of national economies in the countries of N. America and Europe it's impact on and links to our daily lives also grow larger. Medical patient monitoring extends rapidly beyond traditional centers of healthcare profession such as hospitals and doctors' offices into patients' homes and workplaces. It is only a matter of time when consumers will require access to such services in their automobiles, and not only in the case of acute health problems but also on preventive basis. Having health-related functions embedded in their automotive telematics systems and that appreciation of that value can become a decision forming factor for consumers in brand selection process. Such functions could not only help preventing serious accidents from occurring when the driver becomes momentarily inattentive due to fatigue or drowsiness, their intrinsic value is in extending a personal bond between the car owner and the automobile. (Hernandez et al., 1998)

2.4. Vehicle status monitoring

Tachograph (data recorder)

The purpose of the recording equipment is to record, store, display, print, and output data related to driver activities.
This includes:

- monitoring driver activities, (Rest, available or working)
- monitoring driving status, (single driver or crew)
- entry of places where daily work periods begin and/or end, (country, area)
- company locks management, (access to company related data can be locked)
- monitoring control activities, (control authority actions are logged into the recording equipment memory)
- detection of events and/or faults (e.g. more than 4 hours of driving in a row, exceeding 90Km/h)

The recording equipment records and stores data in its data memory and in tachograph cards. This is done in accordance with directive 95/46/EC of 24 October 1995 (95/46/EC, 1995) on the protection of individuals with regard to the processing of personal data and on the free movement of such data.

3. Crash related functions

3.1. Smart Restraints

New concepts for smart restraint systems are concerned with several aspects:
A first objective is to impose and distribute the energy of occupant restraints according to the severity of the impact. The second objective is concerned with pre-crash detection that provides advance warning of impending (forward or side) crashes and will pre-deploy the appropriate air bag(s) in a vehicle prior to the impact to obtain maximum protection for the vehicle occupants. If reliable under all potential impact situations, this might permit slower deployment speeds for the air bags and ultimately more protection for the vehicle occupants.

At last, vehicle inner space monitoring will adapt airbag inflation to the current cockpit situation, i.e. no inflation in case of nobody or baby seat, partial inflation in case of out-of position situations, etc.

4. Post Crash related functions

4.1. Alerting systems

A large number of systems have been developed aimed at alerting the emergency services (e.g. police, ambulance, fire brigades, highway patrols) in case of a traffic incident. Furthermore, some of these systems, e.g. GM's On-STAR, also offer dedicated support services, to which the troubled drivers get connected automatically. Most of the systems feature either a cell-phone technology connection or satellite-based communications. (Benson et al., 1996; Heddebaut et al., 1998)

Alerting systems can either be absolutely automated or require a -more or less-substantial intervention from the driver of the vehicle in emergency. Beyond the notification/alert services, these systems take advantage of the existing infrastructure to bundle a number of other services, including:

- Stolen vehicle tracking;
- Remote door unlock;
- Roadside assistance in case of car breakdown;
- Route support upon request;
- On-STAR services (hotel reservations, restaurants, etc.), from a 250 different services categories and a 4.3 million entries database;
- Remote diagnostics of vehicle malfunctions; and
- Remote driver condition monitoring.

5. Tactical Support functions

5.1. Longitudinal control

Speed control (ISA)

Speed control covers a wide range of different applications, from external speed recommendations to automatic speed reduction (limitation) function, integrated within traffic control systems. The latter may be imposed directly to all the vehicles (or only equipped vehicles, i.e. trucks) within the control area through a Center to call communication or indirectly, by managing the local traffic lights. Stop and go functions may be also included in this category, especially when implemented by an infrastructure-based system. (Oei, 1998b; Davison et al, 1997)

Advanced Cruise Control (ACC)

Longitudinal control ranges from normal cruise control to advanced cooperative intelligent cruise control. Intelligent cruise control senses the presence and relative velocity of moving vehicles ahead of the equipped vehicle and adjusts the speed of travel to maintain a safe separation between vehicles. Vehicle speed is adjusted either by allowing the vehicle to coast or by transmission downshifting. More advanced longitudinal control systems will be capable of detecting a vehicle ahead in the same lane which may be travelling at any speed of may be fully stopped. A full range of braking capability and operating speeds will be available to the equipped vehicle, including stop-and-go traffic operations. (Hayward et al, 2000; Oei 1998a)

5.2. Lateral control

Road departure /lane departure collision avoidance

This feature will provide warning and control assistance to the driver through lane or road edge tracking and by determining the safe speed for road geometry in front of the vehicle. This feature will begin as a driver warning system, and will progress to a capability to provide advice on the necessary actions to safety handle the driving task or control intervention (speed or steering adjustments). The system will warn the driver when the vehicle is (potentially) deviating from the intended lane of travel and will provide advice on the appropriate driver steering or braking response to correct the problem. More advanced capabilities would include an integrated ICC function where vehicle speed could be adjusted on the basis of road geometry (based on inputs from an enhanced map database and navigation system). Furthermore, information from the infrastructure (or in-vehicle sensors) regarding road surface conditions (wet, icy, etc.) could also serve to adjust vehicle speed. Driver inattention during the driving task will be countered with this system, and would ultimately be supported by the driver condition warning service.

5.3. General control

Automatic Stop and Go

The relevant driving task is the automatic stop of a vehicle when such is needed, i.e. when the driver is unable or unwilling to do so. The only thing the users of this system need is increased safety, exactly what the system was intended to provide. This includes a low false alarm rate. (Brand et al., 1997)

IVHS-platooning

This function ranges from full automated platooning, where a number of vehicles is driven driveless on a special road, to platooning, electronically connected to a leading vehicle. The leading vehicle needs a driver and the rest follow it drivelessly. A special case of this function is the tow-bar application, where the vehicles (usually trucks) are electronically coupled and one follows the other. Application areas are usually restricted to highway and motorway network and with a reduced maximum seed limit (usually up to 85 km/h). In case the highway is automatically "driving" the vehicles (in automated platooning) the application is considered to be an Intelligent Vehicle Highway System, (IVHS). (Brand et al, 1997)

Overtake checker

This feature will provide the driver with rear and side information when overtaking.

5.4. Collision avoidance

Rear End Collision avoidance - Pre-crash sensing

This feature will sense the presence and speed of vehicles and objects in the vehicle's lane of travel and will provide warnings and limited control of the vehicle speed (coasting or downshifting) to minimize risk of collisions with vehicles and objects in front of the equipped vehicle. Early versions will extend current intelligent cruise control (ICC) capabilities to areas such as detection and classification of stationary objects and improved determination of lane geometry and occupancy in front of the vehicle (discrimination of threat). Later versions will include increased longitudinal control through vehicle braking, and ultimately the capability to perform combined lateral control and braking actions.

Obstacle detection - pedestrian detection

This system will warn the driver when pedestrians, vehicles, or obstacles are in close proximity to the driver's intended path. This could be accomplished with on-board sensors or infrastructure-based sensors communicating to vehicles. It is also possible that obstacles and pedestrians are provided by a 'bar-code' for presence recognition and identification purposes.

A pedestrian detection system part of a vision system is under development at MIT (USA) (Papageorgiou et al., 1998). This trainable object detection system automatically learns to detect objects of a certain class in unconstrained scenes. One of the tasks is pedestrian detection. This system learns the pedestrian model from examples and uses no motion cues, though the system can easily be extended to include motion information. Pedestrian detection has many possible applications in the areas of automotive assistance systems, image and video database indexing, and surveillance. Trainable techniques will become increasingly important in developing such systems, it is believed.

Intersection collision avoidance

This feature will provide warning to the driver when the potential for collision exists at an intersection. Due to the complexity of the intersection collision problem, it is anticipated that a cooperative vehicle-infrastructure solution will be desired. Complexities include sensing vehicles on intersecting roadways and determining the intent of these vehicles in terms of slowing, turning or potentials for violations of traffic control devices. (Brand et al, 1997)

Rail-road crossing collision avoidance

This feature will provide in vehicle warnings to drivers when they approach a railroad crossing that is unsafe to enter due to approaching or present rail traffic. Initial implementation of this feature is anticipated for buses and trucks carrying hazardous cargo. Extensions to other vehicles may occur when this service is cost-effective. This is likely to occur when this service is integrated with other services.

6. Operational level functions

6.1. Perception

Vision enhancement

Vision enhancement systems can augment the driver's vision under conditions of reduced visibility and hazardous conditions such as fog, rain, snow or darkness. This system requires in-vehicle equipment to sense, process and display the information. Possibilities include improved headlights, infrared and radar sensors. Data collected from road sensors and in-vehicle systems are combined to determine potential collisions. The signal collected from vehicle's sensors is transmitted to an on-board computer that processes the information and compares it to pre-programmed safety limits. Collision warning signals should be displayed on head-up displays (HUD) units or transmitted as audible signals through the vehicle audio system to the driver. Current research projects will verify the feasibility and safety benefits and will develop performance specifications. (Chassant, 2000)

Electronic mirror

This feature would replace conventional door and interior mirrors by an electronic rear vision system based on multiple video sensors. More advanced would propose a digital image processing merging the images into a single homogeneous view displayed onto a central screen.

Such system should provide to the driver a better field of view without being obstructed by pillars, passengers and so. They do not have the blind spots or image distortion associated with large mirrors. However camera image present their own problems to human eye and how the driver perceives those images. i.e. camera doesn't provide the depth of focus of a mirror and forces the driver to determine distances by the relative size of the objects viewed. (EADM, 1999)

Blind Spot detection

Blind spot can be either on the side or behind the vehicle, when low obstacles cannot be seen by the rear view mirror. A warning is given when turning or changing lanes in the presence of other vehicles, cyclists, pedestrians in the blind spot of the driver. A passive or active infrared sensor can be used. A passive sensor senses thermal energy as radiated from the tires of a moving vehicle or bodily heat from persons. This temperature is compared to the temperature of a reference part of the road, e.g. directly behind the vehicle. If no vehicle is in the blind spot, then the two temperatures will be almost the same and no warning is given. Otherwise a flashing LED warns the driver of the presence of a vehicle on the adjacent lane (source: www.alirt.com). Active systems are more expensive. This feature is also concerned with electronic rear view mirror (see previous section).

Reversing Aid / Parking aid

This feature provides information and warning to the driver through short-range obstacle detection and tracking. It helps the driver "see" areas that are currently out of sight and warns the driver of its vicinity to obstacles in enough time to avoid collision.

Such system can be fitted as rear end system (for reverses operation) or as a combined front and rear system for more complex parking operations.

State of the road surface; low friction warning

The state of the road surface condition and/or friction is measured by vehicle sensors or specially equipped sensor vehicles or fixed road sensors. The road surface status or friction information is transmitted a) to the in-vehicle system which warns the driver via audio or visual message and b) to the traffic information centres, who transmit the warnings to other road users as well as winter maintenance operators.

6.2. Man-Machine Communication

Driver convenience communication - 1

This feature will consist of an integrated approach to the driver's in-vehicle interface to external non-driving related information sources. It will include capabilities to support hands-free phone, FAX, car-PC and other wireless service connections, since these features will most likely be available to consumers and must be integrated with IVI features to ensure safety and compatibility among subsystems. (see also next paragraph dedicated to on-board hand-free functions).

Driver convenience communication - 2

The goal is to allow the driver to keep the control of the vehicle with minimum disturbances from these functions, which come in competition with the driving task. Considering all functions which need to be used during driving, for security reasons, it appears to be a must to give the driver the ability to drive them using hands-free feature which means keeping all the time at the minimum one hand on the steering wheel.

Typically, this could be achieved via different means, the better known is vocal interface, but this also could be control on the steering wheel via buttons or tactile surface (Touch-pad).

On-board hands-free functions

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Driver identification and automatic cockpit configuration

Each driver has his/her own physical characteristics, demanding specific adjustments of bottom and back of the seat, steering wheel, rear and side mirrors, air and seat temperature, etc. New cars in the higher price range often have pre-set buttons for a couple of drivers; by pressing a button the specific pre-set adjustments are set automatically. Inserting a personal code can do driver identification. When a data recorder is installed, registering static and dynamic car characteristics, the personal code shall also be registered, so the registered data can be coupled to the driver. A data recorder will have a positive effect on road safety, a reduction of 20% in accidents has been found during an experiment with these recorders installed in vehicles of a fleet owner. Further developments are looking to biometrics identification of the driver: the most promising are based on finger tip and face recognition.

7. Conclusions

Improvement of car occupant safety, comfort and mobility are the main research domains for the automotive industry by the beginning of this new century; with a major challenge, the car safety! This is also why the first level of classification that has been chosen considers three safety-related phases: pre-crash, crash and post crash situations. Most ADAS belong to the pre-crash phase, with some dealing with the post-crash phase. This shows an evolution of the research activity on safety topics. Twenty years ago almost all the research developments were concerned with "passive" (i.e. crash phase) safety. Trying to minimise the crash effect: belts, airbags, mechanical bending structures, etc. are some examples of these developments. Large improvements have been brought in that direction but this is definitively not enough and the objective is now to try to prevent crash situation.

The European road network, too lethal, is close to saturation. The intelligent vehicle concept, which is able to individually and autonomously analyse external and internal data before providing them to the driver, seems to be a first answer to this problem. A majority of the systems and functions described with this state-of-the-art are fully related to these tactical and operational levels. Many of the functions that are described within this state-of-the-art are presented as stand alone functions. Nevertheless it should be underlined that only if several of them are combined in order to generate a more sophisticated integrated system that perform more complicated tasks, will the benefits be significant. A good example is the IVHS/platooning, which is based on a combination of longitudinal and lateral controls.

Another research direction gives a wider field of view. It is related to the concept of intelligent road. The car is not anymore an isolated and autonomous "bubble" but it becomes an interactive tool that provides and receives information from outside through road infrastructure or surveillance centres. A strategic level has now been reached. These new approaches combine different functions as for example navigation, lateral and longitudinal vehicle control to provide the driver with a global and synthetic vision of the environment whether allow the system to take actions instead of the driver. A good example of this approach is given by the *integrated navigation*.

Scope	Type	Description
Pre-Crash	**Navigation based**	Enhanced navigation
		Navigation routing
		Integrated navigation
		Real time traffic and traveller information – distributed navigation
	Man - Machine communication	Automated transactions – electronic toll collection
	Driver monitoring	Driver vigilance monitoring
		Driver health monitoring
	Vehicle status monitoring	Tachograph (data recorder)
Crash	**Smart Restraints**	
Post-Crash	**Alerting systems**	
Tactical Support	**Longitudinal control**	Speed control (ISA)
		Advanced Cruise Control (ACC)
	Lateral control	Road departure /lane departure collision avoidance
	General control	Automatic Stop and Go
		IVHS-platooning
		Overtake checker
	Collision avoidance	Rear End Collision avoidance - Pre-crash sensing
		Obstacle detection - pedestrian detection
		Intersection collision avoidance
		Rail-road crossing collision avoidance
Operational	**Perception**	Vision enhancement
		Electronic mirror
		Blind Spot detection
		Reversing Aid / Parking aid
		State of the road surface; low friction warning
	Man - Machine Communication	Driver convenience communication -1
		Driver convenience communication -2
		On-board hands-free functions
		Driver identification and automatic cockpit configuration

Table 1. Summary Table of Advanced Driver Assistance Systems

It should also be noticed that more and more functions are requiring external supports, through cell phone (GSM) and satellite technologies (GPS or INMARSAT) or others infrastructure support. Most of the time, car manufacturers and suppliers on one side, researchers and public authorities on the other side do not know about each others because their interest are sometimes divergent. The development and "proliferation" of such new functions make necessary the dialogue between these different interlocutors. For automatic collision identification the trend seems to be towards the use of an airbag connected sensor. It seems to be the cheapest solution, as most new cars are equipped with it and the more reliable one, as otherwise many accelerometers need to be installed in many areas of the car, to recognise an impact from all sides.

The above state-of-the-art provided a broad overview of advanced driver assistance systems under development or in some cases already available. These twenty-eight ADAS are summarised in Table 1. Of each system various aspects are being described, from functional description to market impact, and from user needs to strengths and weaknesses of ADAS, though it was not always possible to complete the list in a satisfactory manner, because of lack of information for these new systems.

In addition to the related safety function described within this state-of-the-art some other promising functions have also been identified, which are mainly related to driver convenience topics. Systems sometimes are aimed at compensating the limitations and weaknesses of the human driver, in conducting his driving tasks. For example the automatic transmission takes over the whole manual handling of the transmission, and not only those parts being difficult or tiring for the driver. The question is whether in the long term ITS will go so far as to automate the driving task completely.

The user needs will also change with the introduction of ADA systems. As the driver receives more information in the car than before, the human machine interface is of fundamental importance, to prevent misunderstandings between human and machine and vice-versa. Additionally, as many of the ADA systems being described are in a development or test phase, there is a lack of real life evaluations and impact assessments. In some cases theoretical calculations or simulation studies have been conducted, but the results show a great variation and there is need for further specialised research.

A further problem in assessing the effects of these systems after future introduction is, that the penetration rate will in the beginning be very small. Unless the ADA system behaves like a human driver ("Turing machine"), the effect of the system will depend upon the penetration rate. In the beginning the effect on safety might even be negative. So it may be expected that the effects will be changing in the course of time and specialised research for the identification of this change is considered necessary.

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