

## **AMOK SAFETY LOCK (ASL)**

### **DEVELOPMENT AND DEMONSTRATION OF A NEW FUNCTION FOR THE PREVENTION OF INTENTIONAL VEHICLE MISUSE AGAINST PEDESTRIANS**

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## **ABSTRACT**

Most fatalities and serious injuries in traffic result from accidents caused by human error. Today, a series of driver assistance functions exist to help avoid or reduce the severity of such accidents (e.g. Autonomous Emergency Braking), while still allowing the driver to interrupt the function at any time. This overriding behavior – mandated by the Wiener convention [1] – is particularly important in the case of an incorrect function activation on the part of the vehicle’s system. Due to this built-in override functionality, driver assistance functions – which typically support the driver in de-escalating a critical situation – cannot help preventing cases where drivers actively target pedestrians with the vehicle (as in recent vehicle ramming attacks). This makes clear the need for active safety functions able to prevent the driver from (intentionally or unintentionally) causing harm to other traffic elements. The function Amok Safety Lock (ASL) was developed as a prototype function to research the possibility of increasing the safety of pedestrians in the case of vehicle misuse. The function ASL looks at the driver’s driving behavior, the predicted vehicle’s motion and the relative positions and motions of pedestrians in the vicinity of the vehicle to identify an imminent collision. If the driver does not act to de-escalate the situation, the function initiates an emergency braking maneuver without the possibility of overriding. Simultaneously, warning signals (horn, front and turn lights) are emitted to alarm the pedestrians nearby. This behavior was confirmed in both simulations and vehicle tests using IAV’s Vehicle-in-the-Loop approach. Due to its unilateral behavior, changes in the legal framework are necessary before such a function can be deployed.

## **INTRODUCTION**

### **Motivation**

Advanced Driver Assistance Systems (ADAS) are a key feature of modern vehicles and have contributed to a significant reduction in traffic accidents and traffic-related deaths [2]. One such function is the Autonomous Emergency Braking (AEB), nowadays available for most light and heavy vehicles: it uses environment information gathered by sensors to identify an immediate collision with another traffic element and, if the driver is unresponsive, activates an emergency braking maneuver and relevant safety systems (e.g. safety belt). Due to regulations put in place at both international [1] and national level [3], all ADAS functions are required to allow an override by the driver at any time. Due to this override capability, ADAS-functions are incapable of preventing drivers from causing injuries to other traffic elements (of which pedestrians are the most vulnerable), as demonstrated by the numerous terrorist attacks which saw drivers intentionally targeting pedestrians with vehicles [4]. To prevent such cases a function is necessary that takes control *away* from the driver, a requirement that clashes directly with the need for the permanent possibility of an override.

To bridge these two conflicting requirements and at the same time contribute to the discussion over regulations for advanced driver assistance functions, a new active safety function Amok Safety Lock (ASL) was developed at IAV GmbH, which can unilaterally trigger an emergency maneuver if the driver intention is recognized as nefarious.

## Scenarios

The recent cases of terrorist ramming attacks [4, 9] provide some hints for defining the functional range of the ASL function and therefore to identify the relevant scenarios. Approximately 86% of the fatalities happened in public streets or public gatherings [9]; in all situations, the driver intentionally accelerated while steering to target pedestrians; and it continued to do so even after a first collision (that is, it was not a one-off situation). With these characteristics in mind, a representative scenario was developed and used as reference for the demonstration of the ASL functionality (see Figure 1. The reference scenario for the Amok Safety Lock function: the vehicle leaves the road and targets pedestrians). In this scenario, the driver steers the vehicle outside of the road and targets pedestrians. Taking this scenario as reference, several scenario variations were developed to validate the function's behavior. In these scenarios, the following characteristics were varied and combined:

- On-road vs. off-road
- Driver steering and acceleration/braking behavior
- Avoiding vs. targeting behavior
- Parking speed vs. attack speed
- Relative position of other pedestrians (avoidance maneuver available vs. not available)
- Prediction of pedestrian motion (static vs. dynamic)



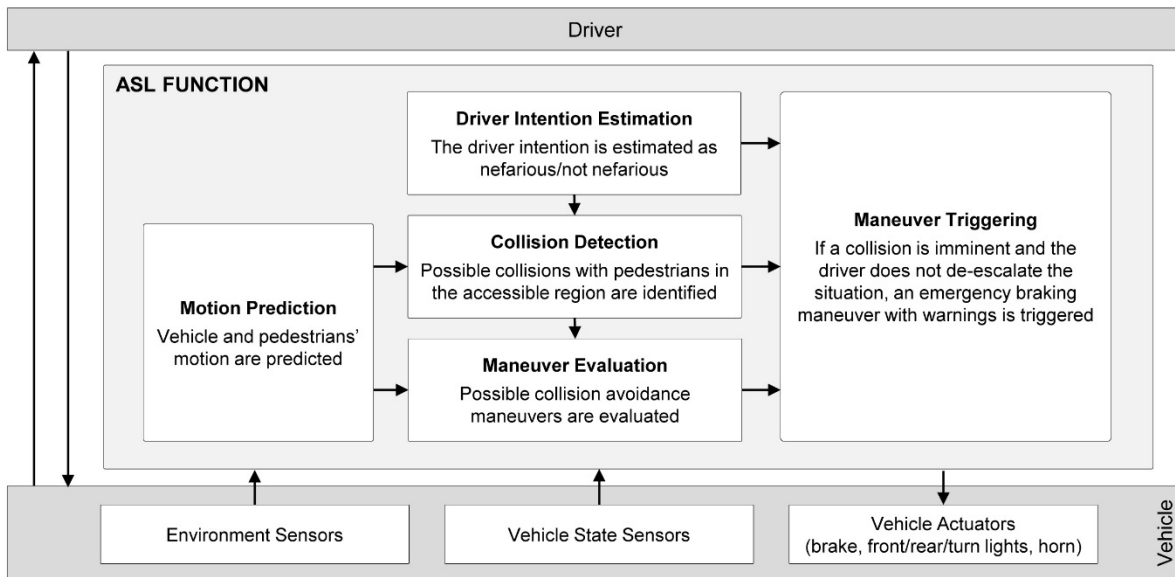
**Figure 1. The reference scenario for the Amok Safety Lock function: the vehicle leaves the road and targets pedestrians**

## FUNCTIONAL ARCHITECTURE

The functional range of the ASL function was initially divided into four high-level requirements:

- a) The driver intention shall be estimated;
- b) Potential collisions with pedestrians shall be predicted;
- c) Potential collision avoidance maneuvers shall be identified;
- d) If the driver's intention is estimated as nefarious (no de-escalation of the situation) and an unavoidable collision with at least one pedestrian is identified (i.e. no collision avoidance maneuvers available), the ASL function shall bring the vehicle into a safe state and trigger warnings to the immediate surroundings, without the possibility of an override by the driver.

The functional architecture of the ASL function closely follows this breakdown and was implemented as illustrated in Figure 2. System overview and main functional blocks of the ASL function. All the functional blocks are executed in real-time such that, should the conditions change, the function can immediately react.



**Figure 2. System overview and main functional blocks of the ASL function**

### Estimation of driver intention

A driver typically de-escalates a dangerous collision situation by braking and/or steering the vehicle away from the collision. To estimate the driver's intention ('requirement a' above), the ASL function monitors the gas and brake pedals, and the steering wheel. The driver's intention is classified as "nefarious" if the driver does not steer the vehicle away from pedestrians and/or does not reduce speed (i.e. does not press the brake pedal). If the driver does act to avoid the collision, no triggering of the emergency braking maneuver takes place, even if his actions are evaluated as insufficient to completely avoid the collision.

To further support the estimation of the driver's intention and minimize the probability of an unjustified ASL triggering (particularly important considering the significant impairment the ASL causes to the driver), two additional criteria are taken into account:

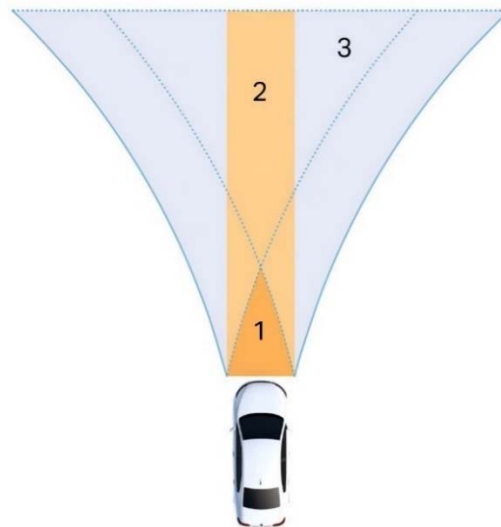
- Information about the road limits (road marks, curb, high-precision positioning) is used to determine if the vehicle is driving *on* or *outside* the road. The ASL function is allowed to trigger a collision avoidance maneuver only after the vehicle leaves the road (vehicle state changes from in- to off-road);
- The vehicle's speed is used to limit the ASL activation: an emergency maneuver can be triggered only if the speed is within a given range (currently 10 km/h – 80 km/h). This helps eliminating cases where the vehicle moves very slowly and accidentally touches a pedestrian (e.g. vehicle driving slowly through a crowd) and general cases where damages are expected to be minor.

### Motion prediction

For the prediction of the pedestrians' motion, and due to the relatively short time-scales involved in typical collision-scenarios (milliseconds to a few seconds), a relatively simple motion model assuming constant speed was used (more complex models are possible [8]). To predict the vehicle's motion the ASL function uses a clothoid-based approach which takes into account vehicle-specific dynamical characteristics to generate a realistic dynamical motion for the particular vehicle [5].

The prediction calculation identifies three relevant regions in the environment around the vehicle (Figure 3. The vehicle's surrounding region is divided into three regions with different criticality.):

- Region 1 – The »most critical« region, which will be driven through with certainty, independently of changes made to the vehicle dynamics;
- Region 2 – The »critical« region, which will be driven through with certainty if the vehicle holds its current state;
- Region 3 – The »latent critical« region, which could be reached if the vehicle changes its current motion.



**Figure 3. The vehicle's surrounding region is divided into three regions with different criticality.**

Region 3 is used to identify all relevant pedestrians - pedestrians which are detected by the sensors outside this region are not considered. Region 2 is used to estimate potential collisions if the driver does not change the current vehicle's motion. Region 1 is used to trigger the emergency braking maneuver: the limits of this region represent the last possible moment at which a collision avoidance maneuver can be successfully undertaken by the driver.

## Collision detection

The identification of a collision with pedestrians ('requirement b') is performed by calculating the intersection of the area swiped by the vehicle during its predicted motion with the area covered by the pedestrian during its predicted motion. Additionally, a distinction is made between an individual pedestrian and a group of pedestrians: if the distance between pedestrians is less than a given threshold (taken as the approximate width of the vehicle), they are considered to be a "group". This group classification is then used in the next step to identify possible collision avoidance trajectories for the vehicle (i.e. trajectories which lead the vehicle between groups).

## Maneuver evaluation

After identifying all possible collisions with pedestrians, the ASL function searches for maneuvers which can avoid the predicted collision (requirement c). To identify an unavoidable collision, the function executes sequentially the following steps (Figure 4. The steps for identification of a collision-free vehicle path (for simplicity the motion of pedestrians is not represented). From left to right: a pedestrian is identified in the vehicle's path; other pedestrians are identified in the accessible region; a collision-avoidance path between groups of pedestrians is determined.):

1. The function determines the predicted presence of at least one pedestrian in the »critical« area (zone 2 in Figure 3). If there are several pedestrians in the critical area, the one closest to the vehicle is taken as reference;
2. The function detects other pedestrians in the »latent critical« area (zone 3 in Figure 3) and separates all pedestrians into groups with at least one pedestrian;
3. The function verifies the existence of trajectories capable of leading the vehicle between the groups of pedestrians without colliding with any of them. Any other objects detected in the vicinity of the vehicle are also considered in this step.



**Figure 4. The steps for identification of a collision-free vehicle path (for simplicity the motion of pedestrians is not represented). From left to right: a pedestrian is identified in the vehicle's path; other pedestrians are identified in the accessible region; a collision-avoidance path between groups of pedestrians is determined.**

If no collision-free maneuver exists at end of step 3, the collision is classified as unavoidable (more exactly: the collision becomes classified as unavoidable shortly before it becomes unavoidable, as to provide sufficient reaction time for the system). As long as no pedestrian is predicted to be in the critical area (step 1) or at least one collision-free maneuver exists (step 3), the function will not perform any action and will not trigger an emergency braking.

## Maneuver triggering

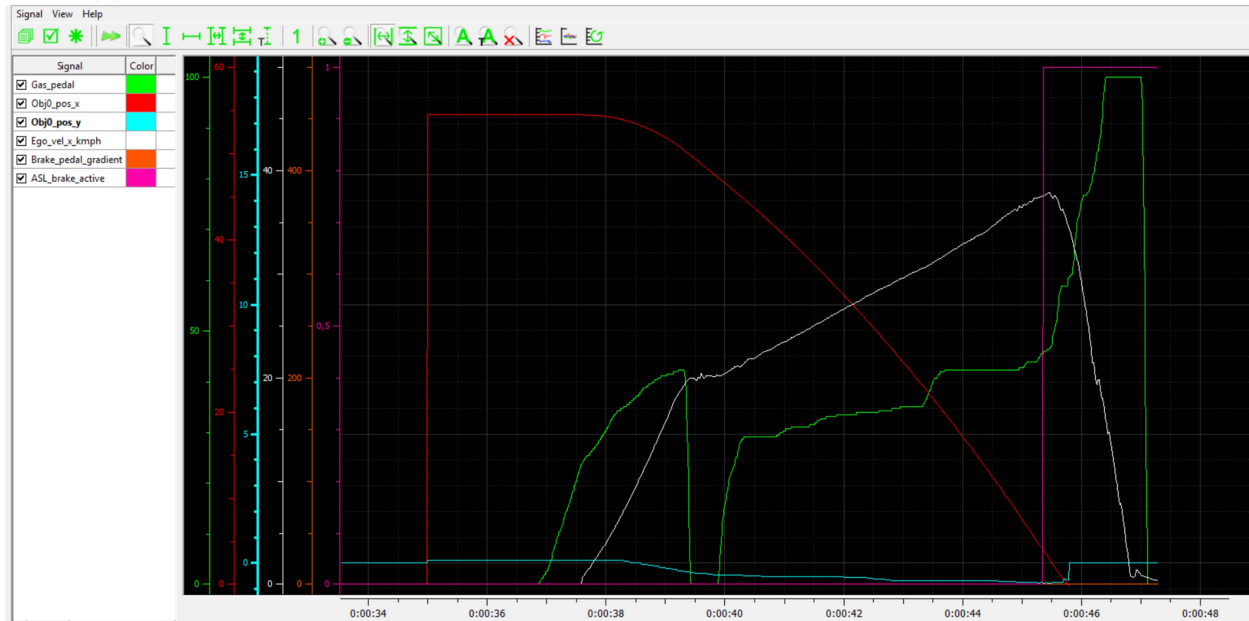
If a collision with a pedestrian is imminent (i.e. the vehicle is about to enter a state where no collision avoidance maneuver is feasible) and the driver does not de-escalate the situation (i.e. does not brake or steer away from collision), the function ASL triggers an emergency braking maneuver without the possibility of driver intervention, effectively bringing the vehicle to a standstill ('requirement d'). Additionally, acoustic (horn) and optical (front, rear and turn lights) warnings are triggered to warn the immediate surroundings about the dangerous driver's behavior.

## VALIDATION

The ASL function was validated concurrently using computer simulations and vehicle tests. While simulations allowed for the exact verification of the function's logic, the validation in a real vehicle allowed the function to achieve a high degree of maturity in a relatively short period of time. This was possible by using IAV's Vehicle-in-the-Loop test approach [6, 7]. In this test method, a real vehicle is fed with virtual traffic objects (in this case pedestrians and roads); virtual sensors then detect the (also virtual) objects and pass this information to the ASL function which, if necessary, commands the (real) actuators to act. The function itself does not run on the vehicle's target hardware but on a standard laptop computer while the tester can observe the scene as seen from the driver's point-of-view in a display fixed to the windscreen (see Figure 5. Inside IAV's Vehicle-in-the-Loop: the test scenario is visualized in a display showing the (real) environment and the (virtual) pedestrians.). The use of this setup allowed to test the ASL function in all developed scenario variations using relatively little resources and without endangering any pedestrians.



**Figure 5. Inside IAV's Vehicle-in-the-Loop: the test scenario is visualized in a display showing the (real) environment and the (virtual) pedestrians.**



**Figure 6. Validation of the ASL function using IAV’s Vehicle-in-the-Loop approach: the vehicle breaks until standstill (left) and simultaneously activates lights and horn (right) even if the driver tries to accelerate.**

A particular important part of the validation was the verification of the function’s full authority, i.e. the demonstration that control over the acceleration of the vehicle was taken *away* from the driver. In Figure 6. Validation of the ASL function using IAV’s Vehicle-in-the-Loop approach: the vehicle breaks until standstill (left) and simultaneously activates lights and horn (right) even if the driver tries to accelerate. are shown the results of such a test case. At first, the driver accelerates (signal “Gas\_pedal”) and continuously reduces the distance to the pedestrian (signals “Obj0\_pos\_x” and “Obj0\_pos\_y”). Once the collision becomes imminent, the ASL function requests a braking maneuver (signal “ASL\_brake\_active”). Despite the driver accelerating (note that the brake pedal is not pressed, see signal “Brake\_pedal\_gradient”), the vehicle slows down to standstill (consequently the engine stalls and shuts down).

## CONCLUSIONS

There have been approximately 78 terrorism-motivated vehicle ramming attacks between 1973 and 2018, from which resulted 281 deaths and approximately 1200 injuries [9]. Even if the number of casualties is not comparable with the casualties due to other causes, the psychological effects on the society at large are significant. The possibility to actively influence the motion of a vehicle opens up possibilities for increasing the safety of pedestrians in addition to the safety of the vehicle’s occupants. Particularly in the case of an intentional misuse of a vehicle it is important to have functionalities capable of avoiding or at least minimise the harm to pedestrians, i.e. some kind of “driver prevention” functionality.

The ASL function monitors the driver’s behavior (steering wheel, brake and acceleration pedals) and the environment. If an imminent collision with a pedestrian is identified and the driver does not maneuver to avoid the collision, the function commands an emergency braking maneuver until the vehicle is brought to a standstill and activates optical (front and turn lights) and acoustical (horn) warnings to the surroundings. Once the emergency braking is activated, the function cannot be overridden by the driver: the vehicle is brought to standstill and warnings are emitted, even if the driver tries to accelerate or maneuver. Tests using IAV’s Vehicle-in-the-Loop approach have demonstrated the correct functioning of the ASL: in the case of an imminent collision, the function

activates and brings a real vehicle to standstill even if the driver accelerates, while activating the acoustic and optical warnings. Furthermore, the use of simulations and Vehicle-in-the-Loop testing back-to-back allowed the function to reach a high maturity level in a short timeframe: while simulations confirmed the correct logic of the function, Vehicle-in-the-Loop tests demonstrated its robustness vis-à-vis the inputs from the vehicle, i.e. the real vehicle dynamics. Because of the nature of the test approach, issues specific to sensors and sensor measurements (e.g. faulty sensor data) were largely not addressed but need to be before such functions can be deployed. With the objective of increasing the ASL function's robustness, several new approaches are currently being evaluated, including new motion models [8] and new methods for determining the vehicle's position relative to the road (e.g. artificial intelligence for curb recognition).

The function ASL is not meant as substitute to existing Autonomous Emergency Braking functions, but as an extension thereof; and while its functionality clearly goes against current vehicle regulations [1, 3], it is also a case in point on how to increase function autonomy while contributing to further reduce the number of casualties caused by (intentional or unintentional) human action. However, changes in regulations are needed before such functionalities are implemented.

Currently, every ADAS function is required to allow an overriding [10]. While this is intended to allow the driver to perform his duties according to road traffic legislation, it does nothing to prevent the driver from going against that same legislation. Legislation is currently being drafted to allow autonomous systems to drive but not to let them *prevent* the human from driving. To effectively give control of a vehicle to the machine instead the human sitting in the driver's seat, both the circumstances in which this can happen as well as the actions allowed to happen have to be very clearly defined. With that in mind, the following regulatory changes could help the deployment of this functionality:

- Definition of the range of vehicle states. Only when the vehicle is in a specific state should any function be allowed to have full authority over any aspect of the vehicle control. The most immediate one is the state where all the necessary sensors are operational. But other ones are possible (e.g. only when no trailer is present), and these should be explicitly laid out;
- Definition of the range of actions. Any function preventing a human user from exerting control over the vehicle shall be allowed to have full authority over only very specific dynamic tasks. In a first step, this influence could extend to longitudinal control and more specifically to deceleration; in a further step, the function could be allowed to also perform lateral control;
- Definition of the range of circumstances. As implemented into the ASL function, full authority over the vehicle (even if just a specific action) should be allowed only in very strict circumstances. These circumstances should be highly critical and explicitly connected with danger to human life in the immediate vicinity of the vehicle.

Apart from these regulatory changes, technical developments are also necessary, especially what concern the certification mechanism for such functions. As it is currently being discussed in the framework of autonomous driving, the current test process should be updated for dealing with the extreme requirements of such a function. Once the test process is accepted at the regulatory and legal level, the question of liability is automatically addressed.

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