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Example for the Application of Safety Models to Define Concrete, Verifiable Performance Criteria

Defining a guideline, outlining what ADS regulations should include, is a necessary and important first step, however it should not be the end of the FRAV process: The more concrete the criteria will become, the more harmonized ADS regulations around the world will become.

As detailed in Document FRAV-26-07, Germany believes that an intermediate step should be chosen before detailing exact performance criteria: proposing a process to come to these criteria using safety models. This idea had been further refined in the "Dynamic Driving Task" workstream of FRAV over the last nine Months, yet a concrete proposal for a process needs to be developed in the next time and neds to be referenced from within the current FRAV guideline document, if annexed to it.

We propose to focus on this work in the following months and discuss the results of this work at the latest in detail at the next FRAV physical meeting (March 2023, Coventry.

To show what exactly could be the outcome of a proposed process, the following is the set of (to a small extent simplified for better explainability, see yellow notes) critical situation requirements from the EU regulation on automated driving, Regulation (EU) No. 2022/1426, formalized in the pseudo-code.

Regulation (EU) No.2022/1426 =

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General

Do not cause accidents &

Follow traffic regulations &

(no collision for $f_{\text{safetymodel,i}}=1$) &

$f_{\text{behaviourmodel,i}}=1$)

Requirements are fulfilled if the ADS does follow all relevant traffic regulations, does not cause accidents, does not have any collisions when the safety models require collision avoidance (however, when collisions are deemed unavoidable, e.g. due to violation of rules by others, collision avoidance is not required), and finally matches the requirements from the behaviour models.

Flexibility: Note that Regulation (EU) No. 2022/1426 allows vehicle manufacturers to use different performance requirements in case there is proof that they would lead to comparable safety.

Scenario dependency: Note that the requirements as shown below are stated in combination with possible scenarios.

Collision avoidance required for cutting in of other vehicles:

In a mathematical & logical sense, for any given situation, there will be a function depending on variables that partly describe scenario, delivering a Boolean "true" (1) or "false" (0) for whether the collision needs to be avoided, and vice versa for whether mitigation is acceptable:

$f_{\text{safetymodel,LaneChange from other vehicle}}$ = [1 for $TTC_{LaneIntrusion} > (v_{rel}/(2\cdot 2.4\text{m/s}^2) + 0.16s)$ & standing passengers; 0 otherwise]

$f_{\text{safetymodel,LaneChange from other vehicle}}$ = [1 for $TTC_{LaneIntrusion} > (v_{rel}/(2\cdot 6\text{m/s}^2) + 0.25s)$ & not standing passengers; 0 otherwise]

/* *This is oversimplified for the sake of clarity, since Regulation (UN) No. 157 defines additional parameters like e.g. the violating traffic must have been visible for a time of 0.72 seconds and others.*

The concrete values for the above equations were derived from the safety model “Last Point to Brake” [1], assuming that a deceleration level of 2.4 m/s^2 can be achieved after a delay of 0.1 s and a ramp up time of 0.12 s after the lane intrusion of the other vehicle (standing passengers are considered to be able to cope with decelerations of 2.4 m/s^2), or 6 m/s^2 after a delay of 0.1 s and a ramp up time of 0.3 s. Note that since during the ramp up time, the brake deceleration increases, thus it is counted half [1] .

The time to collision for start of braking in order to avoid an accident in general is the following:

$$TTC_{Avoid} = \frac{v_{rel}}{2\cdot d} + t_{delay} + \frac{1}{2} t_{ramp-up} \quad (1)$$

with the relative velocity between two objects travelling longitudinally in the same direction v_{rel}, the deceleration d and the ramp-up time to achieve this deceleration $t_{ramp-up}$, assuming linear increase of the deceleration, and a delay before brake intervention t_{delay}. */

Collision avoidance required for leading vehicle slower / braking / standing:

$f_{\text{safetymodel,leading traffic}}$ = [1 for collision avoidance; 0 otherwise]

/* The assumption here is that the automated vehicle, travelling behind a general vehicle, shall be able to avoid all collisions with slower, braking or standing vehicles or traffic participants ahead simply by controlling its own speed in an appropriate manner. */

Collision avoidance required for VRU crossing:

$f_{\text{safetymodel,crossing pedestrian, urban/rural}}$ = [1 for collision avoidance & v_{veh} <= 60 km/h & v_{vru} <= 5 km/h ; 0 otherwise]

$f_{\text{safetymodel,crossing bicycle, urban/rural}}$ = [1 for collision avoidance & v_{veh} <= 60 km/h & v_{vru} <= 15 km/h ; 0 otherwise]

/* The parameters for the equations above are derived from the safety model “Safety Zone” [3] as applied during the development of Regulation (UN) No. 152, assuming a safety zone of 0.65 meters for the pedestrian and a vehicle total width of 2 m (meaning: the vehicle starts to brake when the pedestrian is 0.65 m from the vehicle path), or 3.95 m for the bicycle, which leads to an assumed brake intervention of the ADS at 1.19 s (during which the VRU travels from the beginning of its safety zone to the center of the vehicle path), with a deceleration of 9 m/s^2 and a ramp-up time to achieve this value of 0.54 s, those brake characteristics are in line with the assumptions from Regulation (UN) No. 152. The resulting avoidance speed for these brake characteristics, following equation (1), is then 60 km/h. */

$f_{\text{safetymodel,crossing obscured pedestrian, urban/rural}}$ = [1 for $v_{\text{collision}}$-v_{initial} >= 20 km/h & v_{veh} > 60 km/h | v_{vru} > 5 km/h ; 0 otherwise]

$f_{\text{safetymodel,crossing obscured bicycle, urban/rural}}$ = [1 for $v_{\text{collision}}$-v_{initial} >= 20 km/h & v_{veh} > 60 km/h | v_{vru} > 15 km/h ; 0 otherwise]

/* Following the same considerations as stated above, the speeds are above the calculated avoidance speeds, so avoidance by the ADS *cannot* be expected. However, a speed reduction of 20 km/h for the ADS is expected, which is pragmatically taken from Euro NCAP pedestrian test requirements. */

Behaviour for merging into traffic:

Comparable to the discussions above, in a mathematical & logical sense, for some situations, there could be a function depending on variables that partly describe scenario, delivering a Boolean “true” (1) or “false” (0) for whether the behaviour of the ADS was acceptable. Regulation (EU) No. 2022/1426 explicitly defines the clearance between the ADS and crossing traffic or traffic:

$$f_{\text{behaviourmodel,merging into privileged traffic}} = [1 \text{ for } TTC_{\text{dyn}} > (v_e + v_{\text{a}})/(2 \cdot 3\text{m/s}^2) + 1.5s\text{); 0 otherwise}]$$

/* The concrete values for the above equations were derived in principle from the safety model “Careful and Competent Human Driver” [2], assuming that a comfortable deceleration level of 3 m/s² can be achieved without ramp-up of the deceleration, but within a reaction time of the careful and competent human driver of 1.5 s. These braking considerations are valid for the other vehicle, already traveling in the lane where the automated vehicle merges into. */

Behaviour for crossing traffic:

$$f_{\text{behaviourmodel,crossing privileged traffic}} = [1 \text{ for } TTC_{\text{dyn}} > (v_{\text{c}})/(2 \cdot 3\text{m/s}^2) + 1.5s\text{); 0 otherwise}]$$

/* The considerations here are the same as above: The manual driver of the other vehicle needs to be able to comfortably brake for the crossing vehicle, thus the time to collision between both vehicles shall never fall below the value as given above. */

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Safety Models Taken Into Account

Information from the following concepts has been used:

- [1]: Last-Point-to-Steer (LPS, Ref.: AEBS HDV 03.03).
  - *This model assumes an emergency braking intervention in longitudinal traffic is justified as soon as a collision cannot be avoided by steering (=the last past to steer has passed). Typically the last point to steer for speeds > ca. 30 km/h is later than the last point to brake.*
- [2]: Careful & Competent human driver (CC, Ref.: UNECE Reg. 157 Annex 3 §3.3).
  - *This model assumes the characteristics of a typical driver with regard to threat detection, reaction time delay, brake application to identify what a human intervention to e.g. a cut-in maneuver would be.*

- [3]: Safety Zone (SZ, Ref.: AEBS HDV 03.03).
  - *This model assumes an emergency braking intervention with cross-traffic is justified as soon as the collision partner is no longer able to not enter the path of the ego vehicle AND a collision will occur. In particular for pedestrians, a safety zone of approx. 30 cm is a typical value and this is consistent with the brake distance required for a 5 km/h pedestrian.*