Minimum Risk Manoeuvres (MRM)
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Aim:
Minimise risk in case that the driver does not take over steering control after a transition demand

Rationale:
Depending on the traffic situation and the ACSF category the vehicle shall reach a state in which it produces as less danger as possible for the vehicle occupants and the other road users

Solution:
MRM
2 different cases (root causes) of a Minimum Risk Manoeuvre

**Case A**
Conditions for a safe operation of ACSF are fulfilled

System detects that the Driver is inactive

**Case B**
Conditions for a safe operation of ACSF are **not** fulfilled

System failure or System boundaries reached

Transition Demand

No reaction of the Driver

Minimum Risk Manoeuvre
Case A - Conditions for a safe operation of ACSF are fulfilled

ACSF must comprise MRM, i.e. some strategy to reach a status with as less risk as possible in the given traffic situation, e.g. by:

- Further lane keeping for a certain time
- Enlarging gap to other road users
- Cancel motor power and decelerate smoothly
- Slowing down to standstill
- Switching hazard lights on
- If lane change is part of ACSF's system functionality: lane change to edge of the road
Case A - Conditions for a safe operation of ACSF are fulfilled

Proposal for MRM that an ACSF must at least comprise
(corresponding tests in brackets)

CAT A
• Stop immediately (TR 0)

Cat B
• Hazard lights on + Stop safely in the current lane (TR 1 and TR 2)

CAT C
• Hazard lights on + Stop safely in the current lane (TR 1 and TR 2)

CAT D & E
• Hazard lights on + Leave overtaking lane(s) and stop safely on the most outer available right (left) lane, if traffic situation allows, otherwise stop safely in current lane (TR 1 and TR 2 and TR 3)
Case B – Cond. for a safe operation of ACSF are not fulfilled

Case B1: automatic steering is not possible anymore

ACSF must comprise MRM, i.e. some strategy to reach a status with as less risk as possible in the given traffic situation, e.g. by:

- Failure warning
- Transition demand
- Keeping last steering angle for a certain time
- Cancel motor power and decelerate smoothly
- Slowing down to standstill
- Switching hazard lights on
Case B – Cond. for a safe operation of ACSF are not fulfilled

Case B2: protective braking is not possible anymore

ACSF must comprise MRM, i.e. some strategy to reach a status with as less risk as possible in the given traffic situation, e.g. by:

- Failure warning
- Transition demand
- Keeping lane for a certain time
- Cancel motor power and decelerate smoothly
- Slowing down to standstill
- Switching hazard lights on
Corresponding Tests
TR 0 (driver does not control remote device, switch or button anymore; control too far away)

Check minimum risk manoeuvre

Drive with ACSF CAT A activated
i) Driver releases the control device or switch
ii) Max range of remote control is exceeded

Test is passed:
• Vehicle comes to standstill within [1] s
TR 1 (tight curve: $a_y$ beyond system boundaries)

Check transition demand and minimum risk manoeuvre

- drive on a track with road markings of good visibility (acc. ECE-R 130, Annex 3) at each side of the lane at a speed of 10 km/h below $v_{\text{max}}$ or 80 km/h whatever is lower (test track availability reasons see next slide)
- after a straight section of at least 200 m the vehicle shall approach a curve of more than 90° that would demand an $a_y$ of more than 3 m/s²
- test driver shall not take over manual steering control again before the minimum risk manoeuvre is finished

Test is passed:

- transition demand was given at least when the lateral acceleration exceeds 3 m/s²
- the minimum risk maneuver was finished: hazard lights are activated and vehicle comes to standstill
- vehicle did not cross any lane marking before the minimum risk manoeuvre was finished

or
- Vehicle has by itself reduced speed such that 3 m/s² are not exceeded
Justification for 3 m/s²

- 3 m/s² at 120 km/h correspond to a curve radius of 370 m (test track available?)
- 3 m/s² at 76.4 km/h test speed correspond to a curve radius of 150 m (test track should be available)
- Minimum curve radii (Germany) from Road Construction Directive are:

<table>
<thead>
<tr>
<th>V [km/h]</th>
<th>$R_{\text{min}}$ [m] @ 6%*</th>
<th>$R_{\text{min}}$ [m] @ 2,5%*</th>
<th>$a_y$ [m/s²] @ 6%*</th>
<th>$a_y$ [m/s²] @ 2,5%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>280</td>
<td>930</td>
<td>1.76</td>
<td>0.53</td>
</tr>
<tr>
<td>90</td>
<td>370</td>
<td>1200</td>
<td>1.69</td>
<td>0.52</td>
</tr>
<tr>
<td>100</td>
<td>470</td>
<td>1500</td>
<td>1.64</td>
<td>0.51</td>
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<tr>
<td>120</td>
<td>720</td>
<td>2300</td>
<td>1.54</td>
<td>0.48</td>
</tr>
<tr>
<td>130</td>
<td>900</td>
<td>2700</td>
<td>1.45</td>
<td>0.48</td>
</tr>
</tbody>
</table>

*Cross slope of the lane

=>With a max $a_y$ of 3 m/s² the systems have enough safety margin to manage all curves also with ACSF; normal driving with ACSF with appropriate speed would never cause lateral accelerations of 3 m/s² or beyond on usual roads.
Justification for 3 m/s$^2$

- Up to 3 m/s$^2$ is within the comfort zone for normal driving
- Up to 4 m/s$^2$ would still be within the linear region of tire response
- 3 m/s$^2$ marks about 1/3 of maximum achievable lateral acceleration of a tire on dry roads
- On dry roads ($\mu = 1.0$), 3 m/s$^2$ leaves 9.5 m/s$^2$ for longitudinal deceleration
- On wet roads ($\mu = 0.7$), 3 m/s$^2$ leaves 6.2 m/s$^2$ for longitudinal deceleration
TR 2 (missing lane marking)

Check transition demand and minimum risk manoeuvre

- drive on a circle track (radius such that the lateral acceleration is between 0.5 and 3 m/s² for the given test speed) with road markings of good visibility (acc. ECE-R 130, Annex 3) at each side of the lane at a speed of 10 km/h below \( v_{smax} \) or 80 km/h whatever is lower
- the circle shall have a section of 90° with only one lane marking at the driver's side
- test driver shall not take over manual steering control again

Test is passed:

- the transition demand is given before the vehicle is entering the section with missing lane markings and the minimum risk manoeuvre was finished: hazard lights are activated and vehicle follows the initial path and vehicle comes to standstill or
- the vehicle follows the initial path for the complete section with only one lane marking without crossing any lane marking.
TR 3 (blocked lane)

Check transition demand and minimum risk manoeuvre

• drive on a track with 2 lanes with road markings of good visibility (acc. ECE-R 130, Annex 3) at each side of the lanes at a speed of 10 km/h below $v_{smax}$
• after a straight section of at least 200 m the vehicle shall approach a section where its the lane is blocked and the adjacent lane is blocked 100 m ahead
• test driver shall not take over manual steering control again

Test is passed:
• the transition demand is given at a TTC of [2 s] before the first blocking and the minimum risk manoeuvre was finished: hazard lights are activated and vehicle does a lane change and comes to standstill in the adjacent lane without collision with the second blocking
TR 4 (failure)

Check failure warning, transition demand and minimum risk manoeuvre
• drive on a circle track (radius such that the lateral acceleration is between 0,5 and 3 m/s² for the given test speed) with road markings of good visibility (acc. ECE-R 130, Annex 3) at each side of the lane at a speed of 10 km/h below \( v_{s_{\text{max}}} \)
• Induce a failure of the ACSF (A: steering failure, B: protective braking failure)
• test driver shall not take over manual steering control again

Test is passed:
• A: the failure warning is given and the transition demand is given latest 1s after the failure was induced and the minimum risk manoeuvre was finished: hazard lights are activated and vehicle follows the initial path curvature and the vehicle comes to standstill within 90°
• B: the failure warning is given and the transition demand is given latest 1s after the failure was induced and the minimum risk manoeuvre was finished: hazard lights are activated and vehicle stays in the lane and the vehicle comes to standstill within 90°