Validation Method : Virtual Testing

IWG AEBS - UTAC

J. Vergnaud – A. Piperno – F. Herveleu

Agenda

UTAC CERAM

- Virtual testing activities already in progress
- Discussions on going for validation methods
- Automated Driving applications
- Next steps

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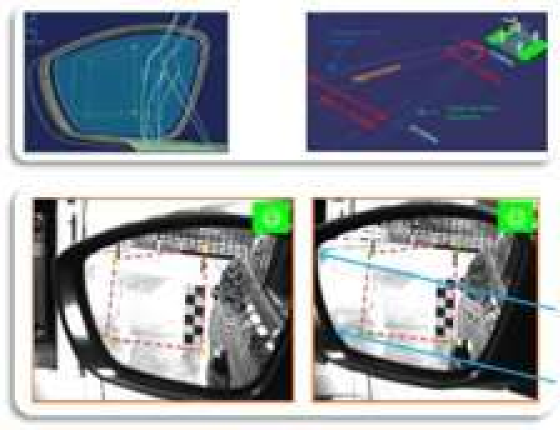
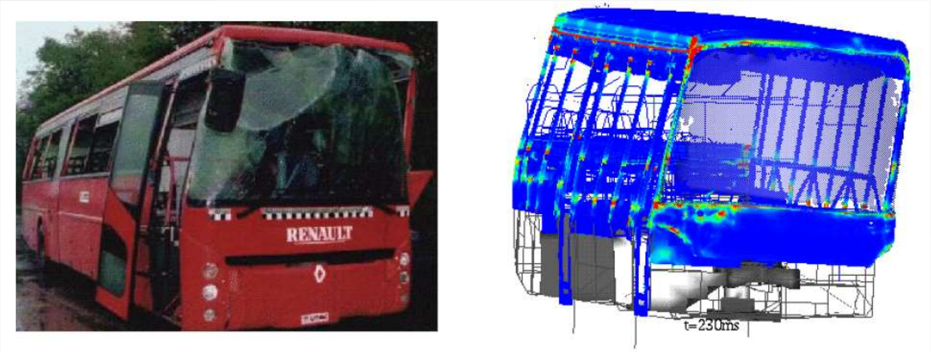
Virtual testing activities already in progress

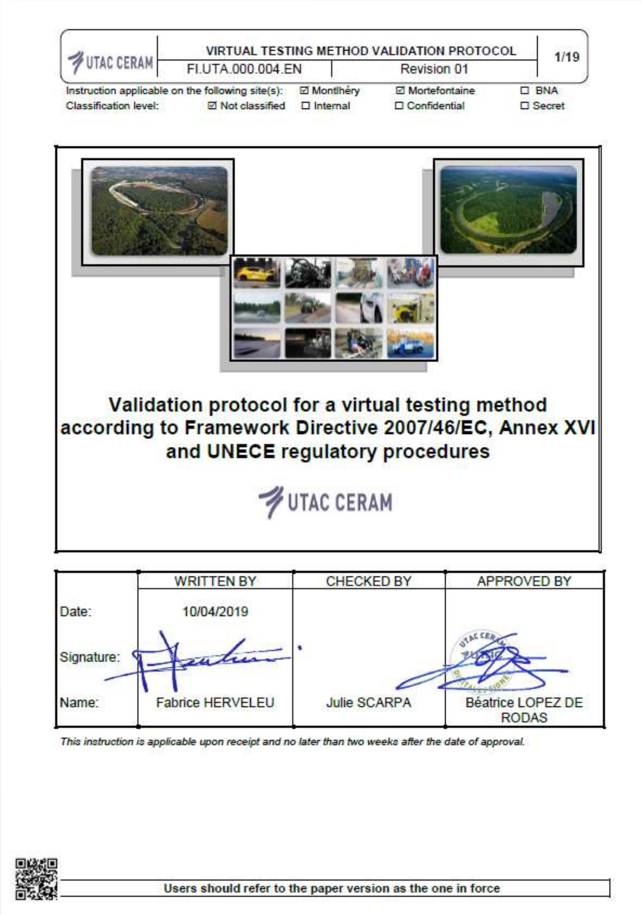
Virtual testing already in use for alternative testing solutions according to regulations or to European approval framework for motor vehicles

- 2007/46 annex XVI or 2018/858 annex VIII defining the specific conditions required from virtual testing methods and regulatory acts for which virtual testing methods may be used by a manufacturer or a technical service
  - UNECE n° 46 on indirect vision
  - UNECE n° 125 on forward field of vision
  - UNECE n° 21 on interior fittings
  - UNECE n° 66 on strength of superstructure of large passenger vehicles





Virtual testing activities already in progress



UTAC CERAM	VIRTUAL TESTING METHOD VALIDATION PROTOCOL		1/19
	FI.UTA.000.004.EN	Revision 01	

Instruction applicable on the following site(s): ☑ Montlhéry ☑ Mortefontaine ☐ BNA
Classification level: ☑ Not classified ☐ Internal ☐ Confidential ☐ Secret

Validation protocol for a virtual testing method according to Framework Directive 2007/46/EC, Annex XVI and UNECE regulatory procedures

UTAC CERAM

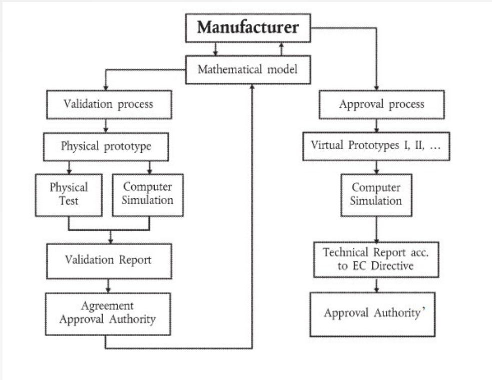
	WRITTEN BY	CHECKED BY	APPROVED BY
Date:	10/04/2019		
Signature:			
Name:	Fabrice HERVELEU	Julie SCARPA	Béatrice LOPEZ DE RODAS

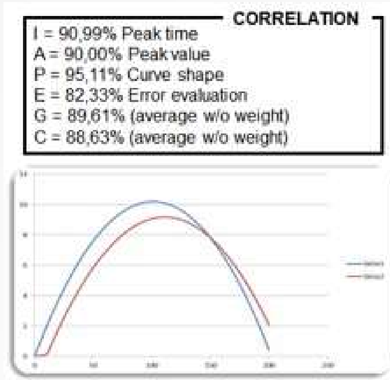
This instruction is applicable upon receipt and no later than two weeks after the date of approval.

Users should refer to the paper version as the one in force

Virtual testing already in use for alternative testing solutions according to regulations or to European approval framework for motor vehicles

- UTAC protocol defined for virtual testing application : validation methodology of virtual testing method focusing on objective evaluation of a correlation level.
- Objective evaluation based on different evaluations between physical and numerical results under a validity area depending on the application :
  - Kinematics
  - Scalar Values
  - Curves using IAPE method (peak time, peak value, curve shape, error evaluation)





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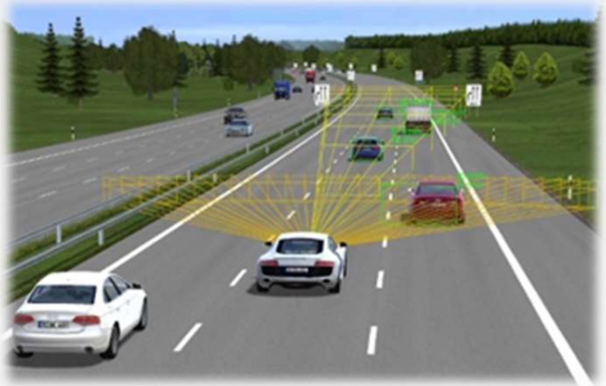
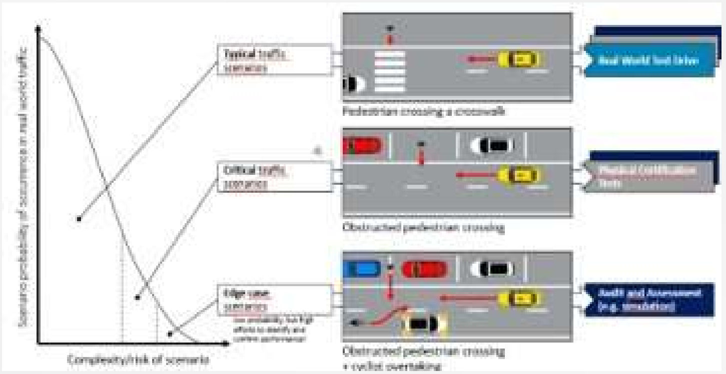
Discussions on going for validation methods

UTAC CERAM

Dedicated Informal Working Group of GRVA for validation methods (VMAD)

- Virtual testing considered as part of the audit/assessment of vehicles with automated mode
    - Safety principles evaluation & validation
    - Critical situations to be evaluated
    - High number of situations to be covered





Discussions on going for validation methods

Dedicated Informal Working Group of GRVA for validation methods (VMAD)

- New regulation on Automated Lane Keeping Sytems (ALKS) annex 4 (functional and operational safety) § 4.2. :
  - Simulation tool and mathematical models for verification of the safety concept may be used in accordance with 1958 Agreement, in particular for scenarios that are difficult on a test track or in real driving conditions.
  - Manufacturers shall demonstrate the scope of the simulation tool, its validity for the scenario concerned as well as the validation performed for the simulation tool chain (correlation of the outcome with physical tests).
- Similar approach and application for lager AD functions implementation.

Agenda

UTAC CERAM

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Context : virtual testing tools

Software In the Loop (SIL)	Hardware In the Loop (HIL)	Vehicle In the Loop (VIL)	Reality

Software In the Loop (SIL)
- **100% numérique**
- **Utilisation de modèles**

Hardware In the Loop (HIL)
- **Essai composants**
- **Environnement émulé**

Vehicle In the Loop (VIL)
- **Essai sur véhicule complet**
- **Environnement émulé indoor/outdoor**

Reality
- **Essai sur véhicule complet**
- **Environnement réel (piste/route ouverte)**

- UTAC involved in Working Group **Euro NCAP Virtual testing**
- UTAC involved in **WMAD traffic scenarios**
- **Member of P.E.A.R.S initiative**: Prospective safety performance assessment of pre-crash technology by virtual simulation
  - ISO assessment method of active safety simulation

Context : tools becomes necessary for ADAS-AD validation

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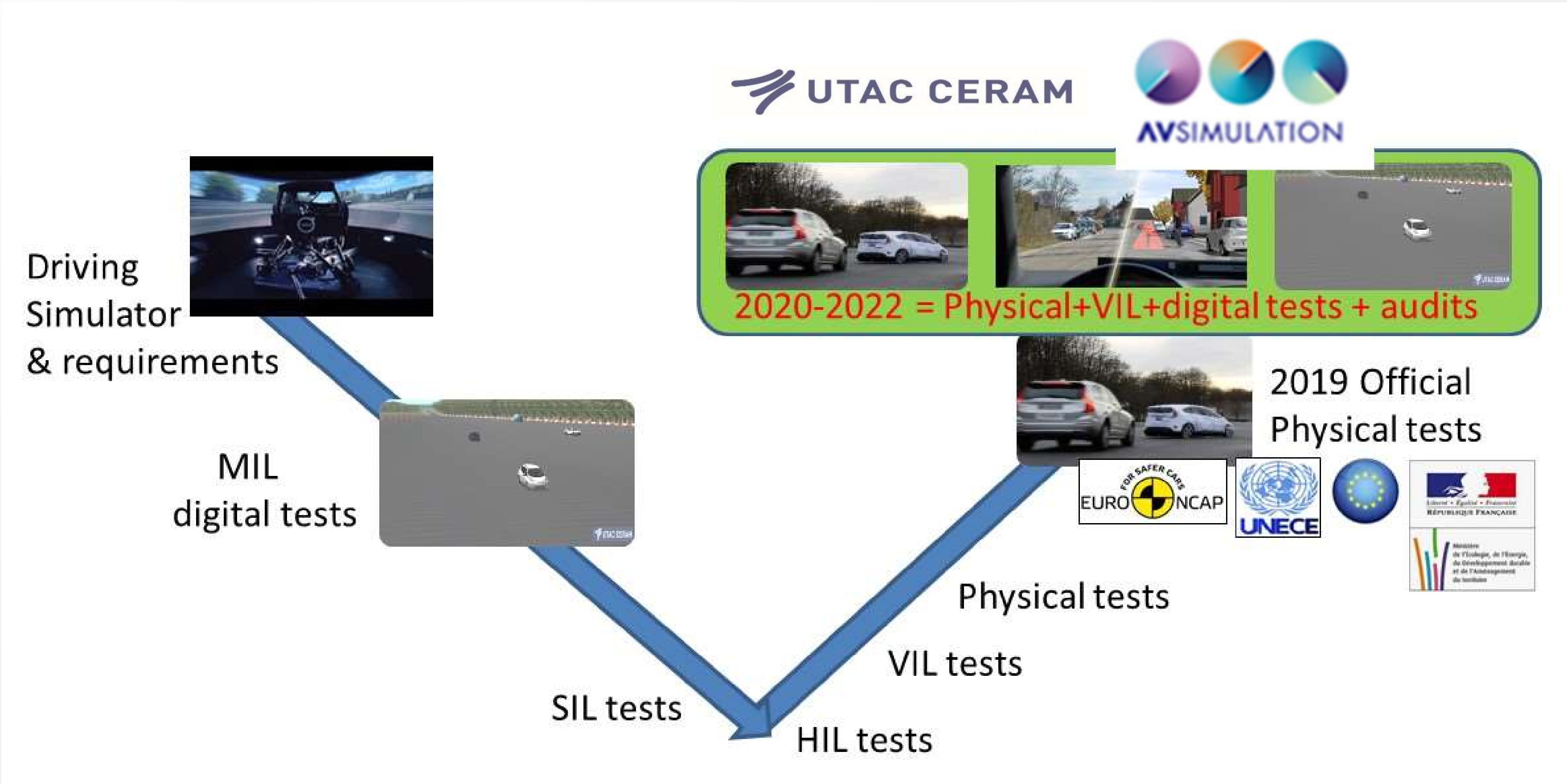
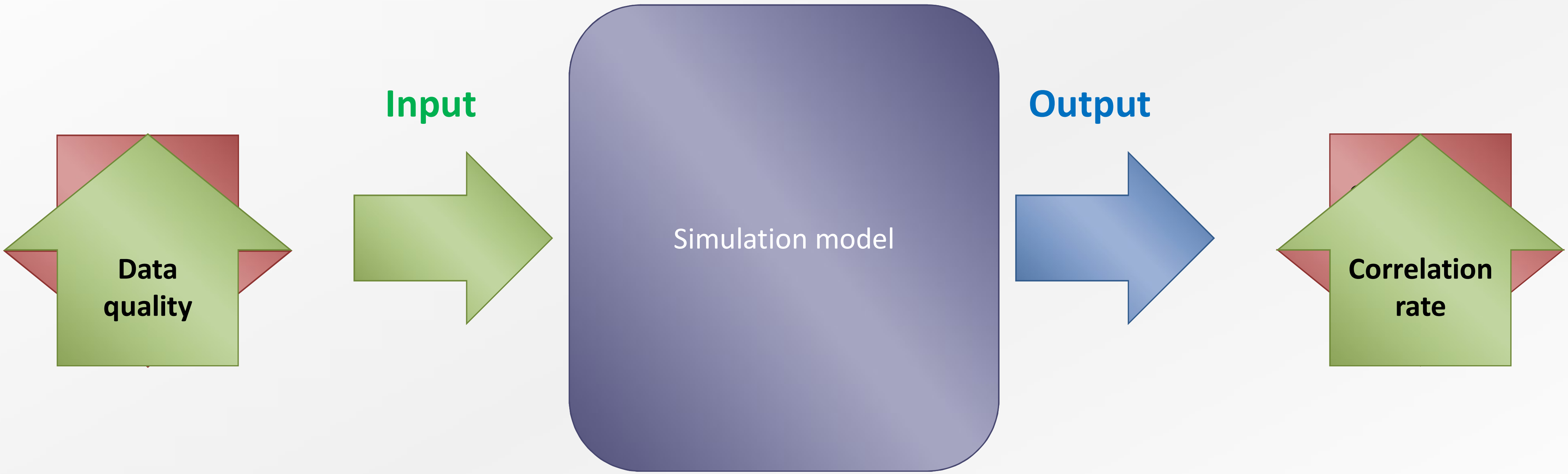
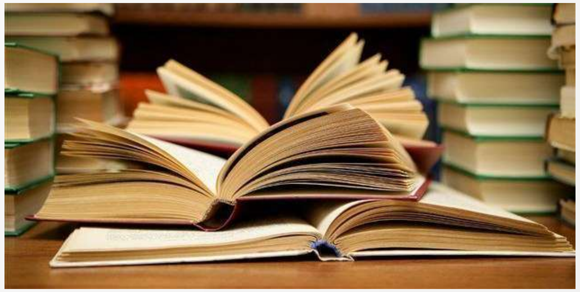


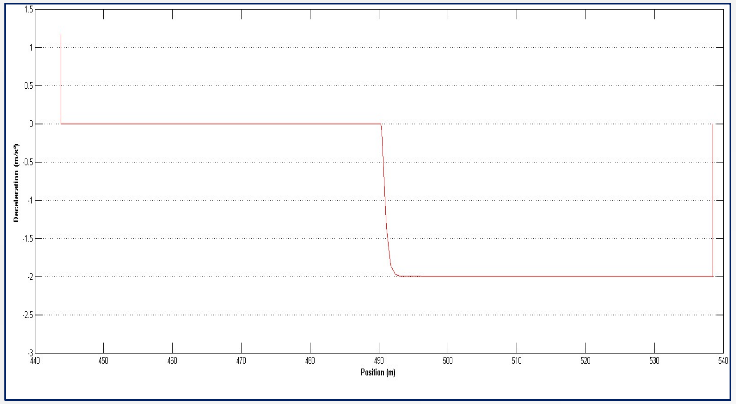
A good input mean a good correlation rate

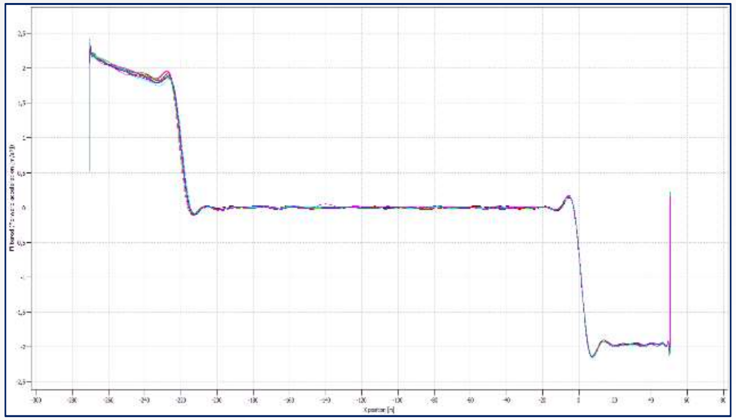


Injecting real test data into scenarios…

Test Protocol spécifications

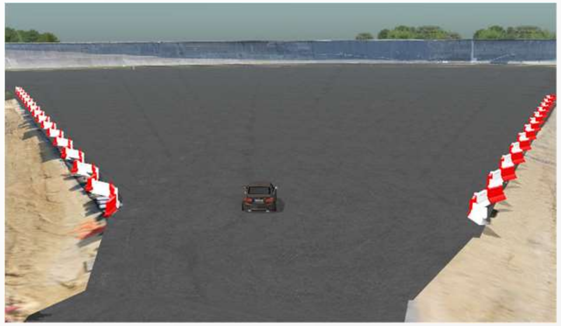






… provides results very close to reality

UTAC CERAM AVSimulation



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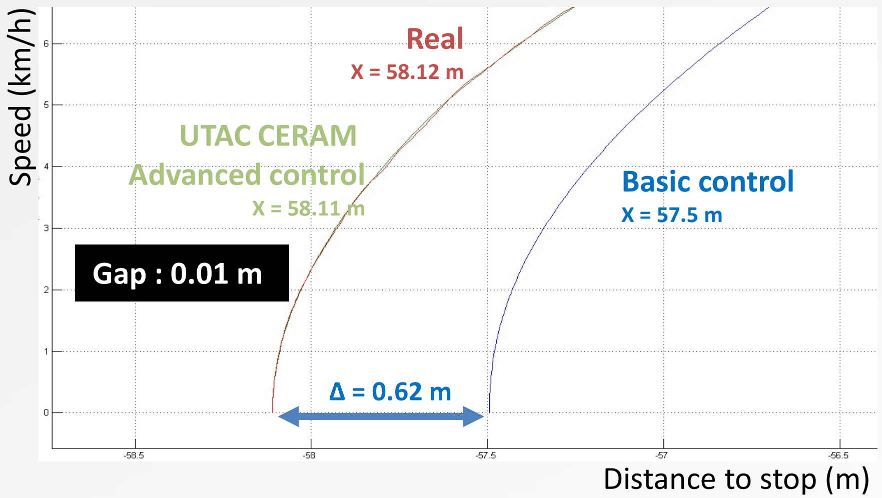
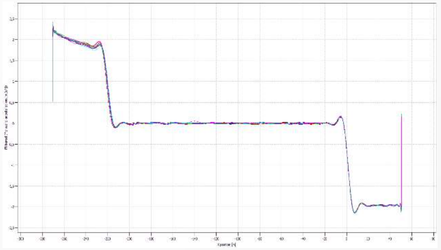
Simulation model

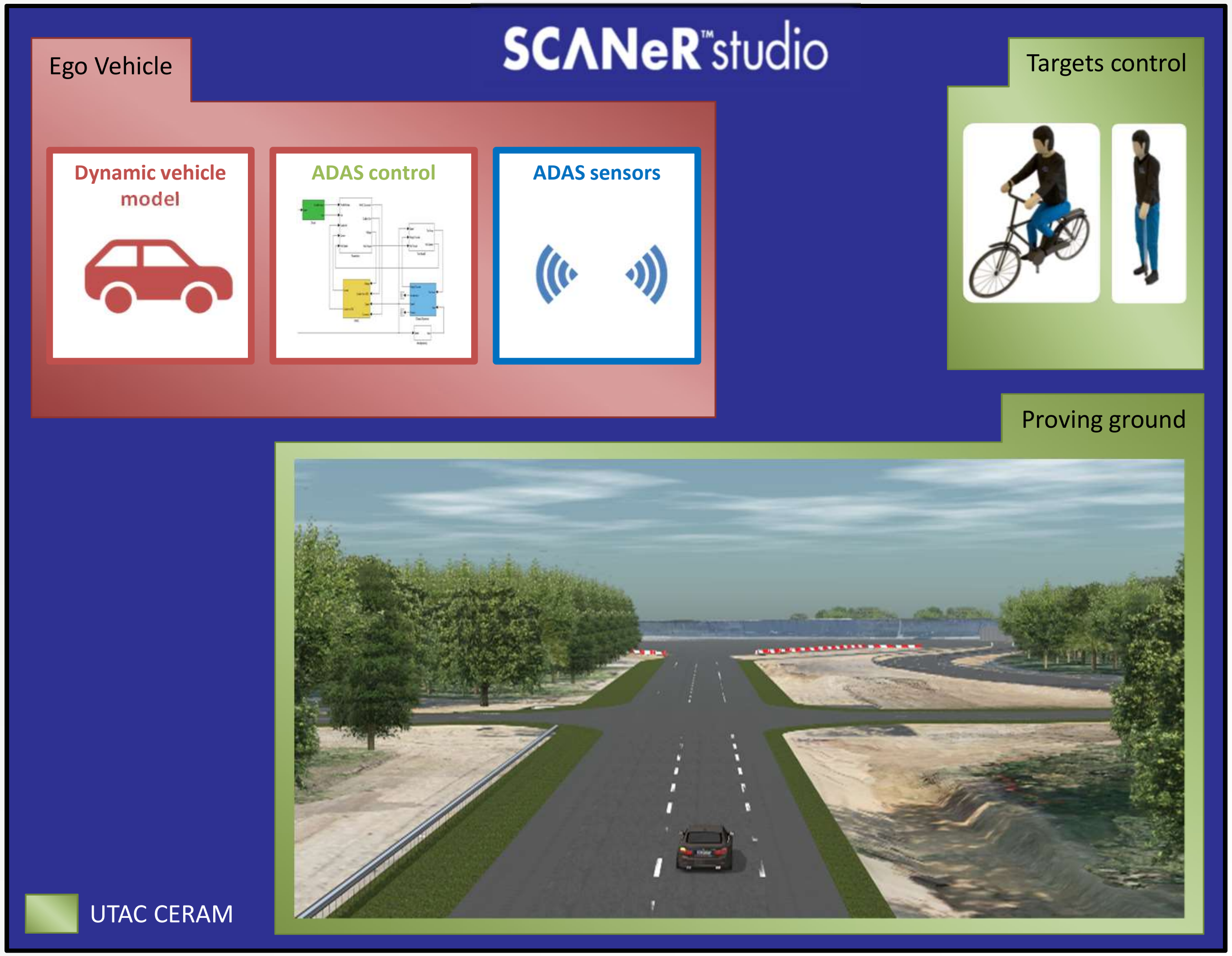


UTAC CERAM expertise in target control & proving ground

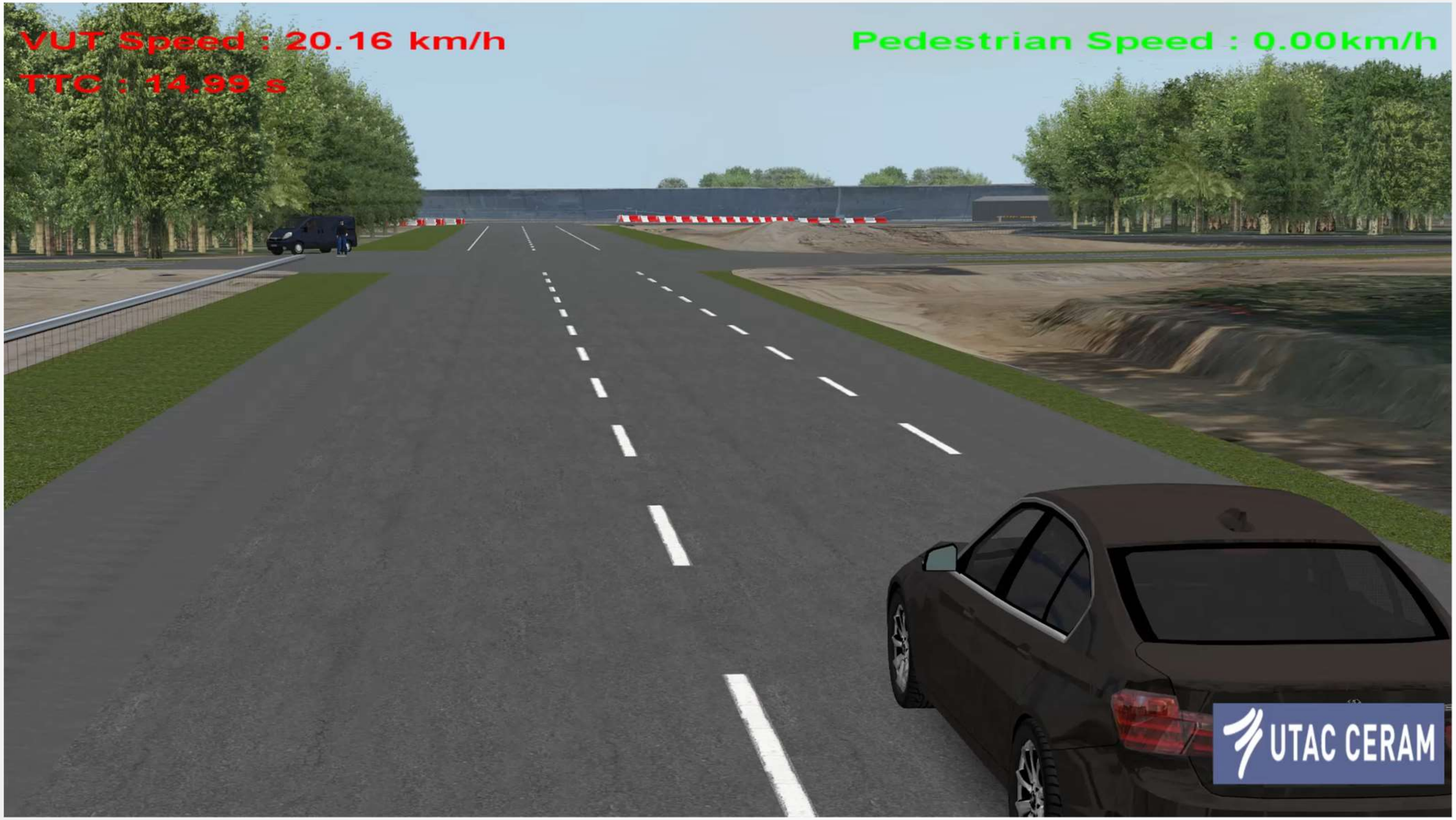
UTAC CERAM AVSimulation



UTAC CERAM Trajectories
Event timeline



Example of correlation : Pedestrian turning scenario

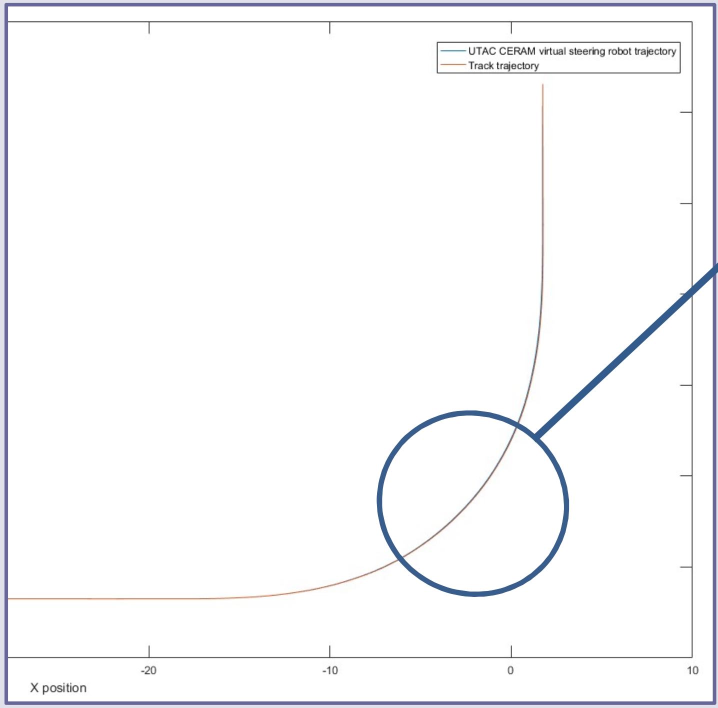


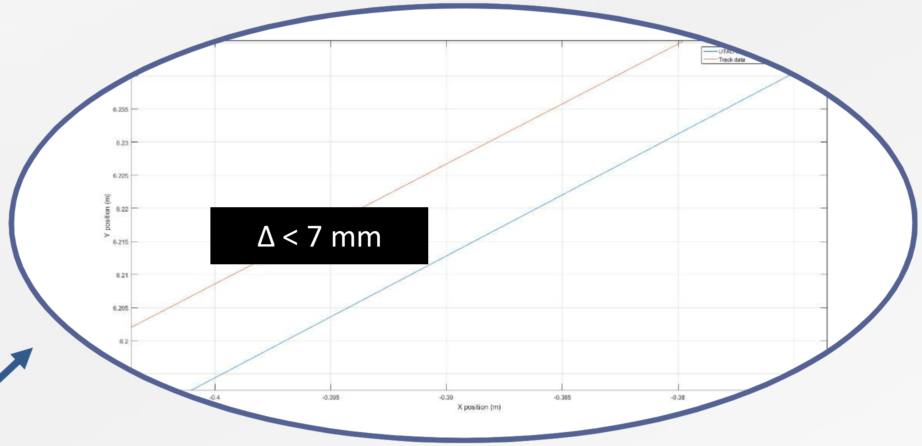
Example of correlation : Pedestrian turning scenario

UTAC CERAM AVSimulation

UTAC CERAM driving robot model control Vehicle Under Test

Ego vehicle pedestrian turning scenario trajectory





- **Trajectory definition in test protocols**
  - Design to be use by robot control software on track
- **Difficult to design without real input**
- **Theorical scenarios haven't real trajectories**
  - UTAC CERAM have real trajectories

4 Steps methodology

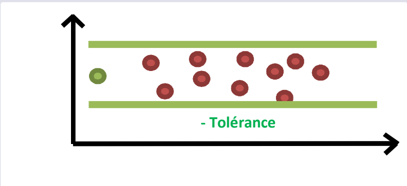
- Methodology use availability: is the vehicle reproductible ?
- Find physical mean value to compare
- Output correlation rate of each variables
- Output final correlation rate: process **validated** or **not validated**

Step 1

10 tests / scenario

Mean value of impact speed or remaining distance

10 values have to be in corridor



Step 2

Step 3

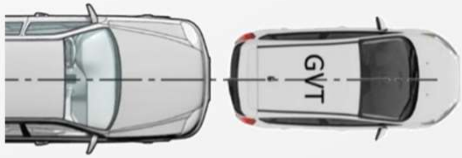
Step 4

Necessity to check if physical is reproductible

- UTAC CERAM have tested 2 vehicles, with different scenarios

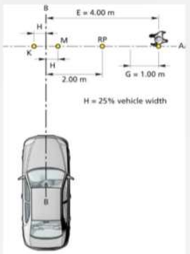
same vehicle
2 different scenarios

Car-to-Car Rear Stationary (CCRs)
100% overlap

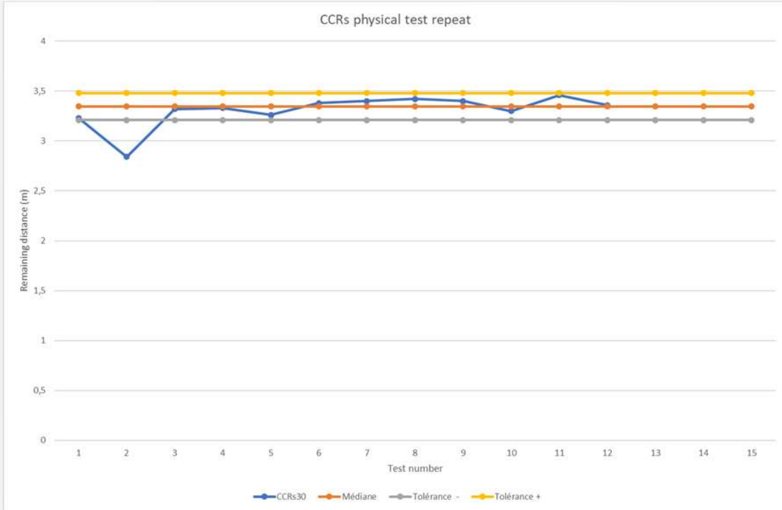


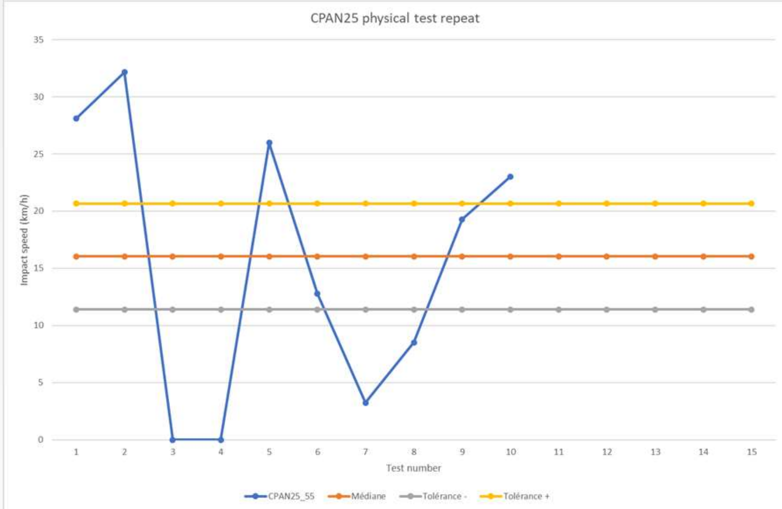
Test vehicle speed: 30 kph
Target vehicle speed: 0 kph

Car-to-Pedestrian Nearside Adult 25% (CPAN25)



Test vehicle speed: 55 kph





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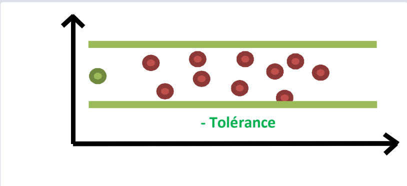


Step 2

10% of real tests can be taken away (an absurd point)

Mean value to compare to simulation

Step 3

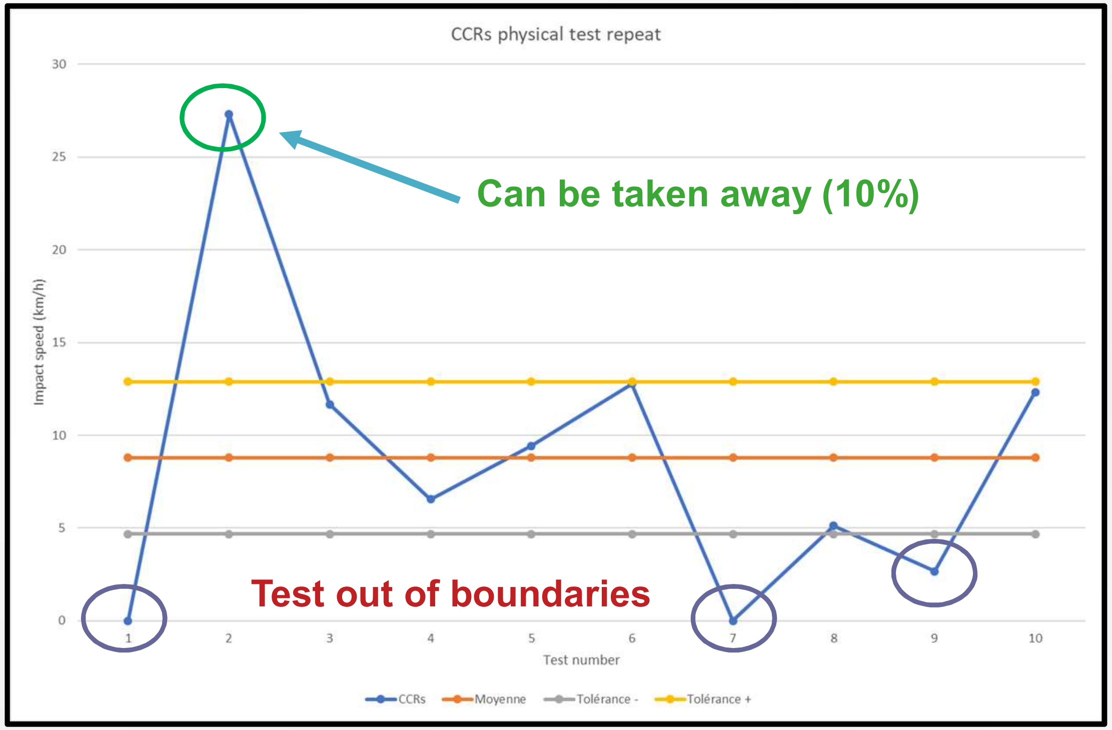
Step 4

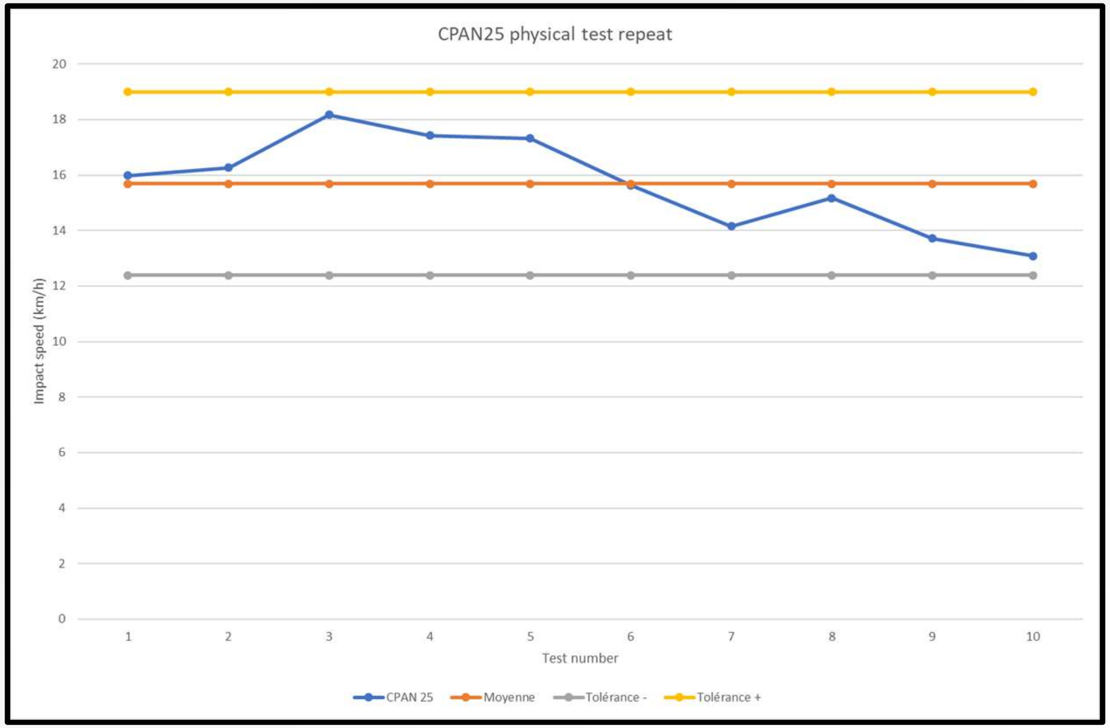
Virtual validation can be applied in a validity domain

UTAC CERAM

UTAC CERAM step 1 apply → Vehicle tested in UTAC CERAM: 10 tests repeated each scenario

- Car to car validity domain: **NOK**
- Pedestrian validity domain: **Ok → Full methodology can be apply**

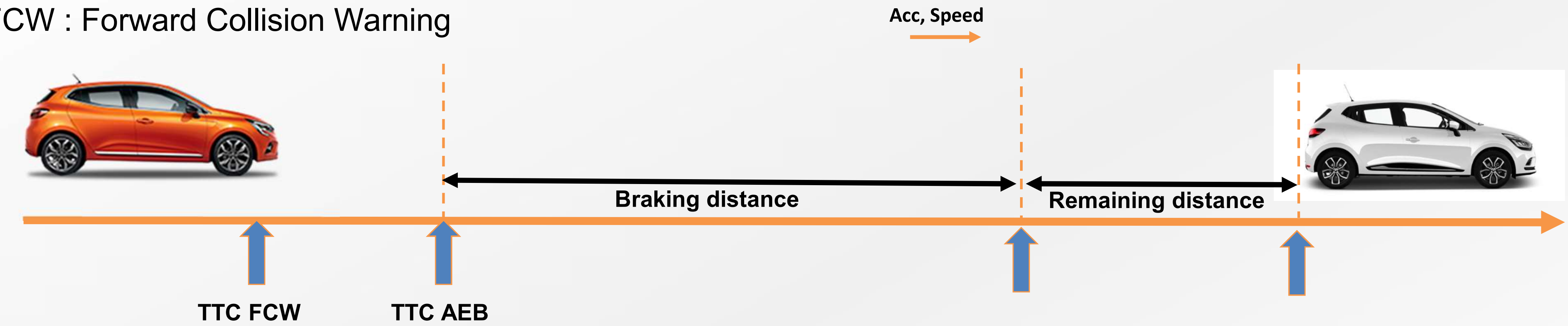


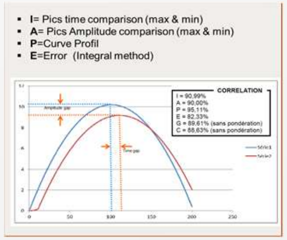


The UTAC numerical procedure applied on AEB

UTAC CERAM

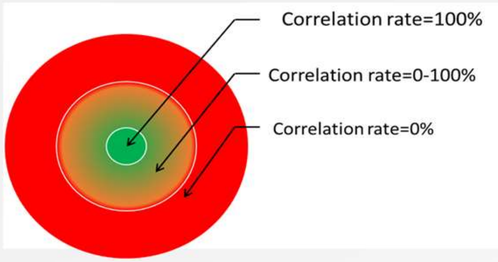
TTC : Time to collision
FCW : Forward Collision Warning





IAPE Method

- Vehicle Speed
- Acceleration



Double thresholds method

- Remaning distance
- Impact Speed
- TTC AEB
- TTC FCW

If A < X < B → 100 %
Else → 0 %

Interval Method

- Lateral distance
- Relative distance

4 Steps methodology

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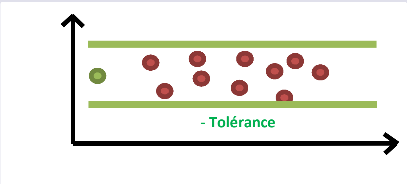


Step 2

10% of real tests can be taken away (an absurd point)

Mean value to compare to simulation

Step 3

- **13 variables** (speed, accel, remaining distance, lateral deviation, stop distance, impact speed, TTC AEB, TTC FCW)
- **3 methods to compare** :
  - IAPE method : peaks, times, amplitudes, curves
  - Double thresholds method
  - Interval method

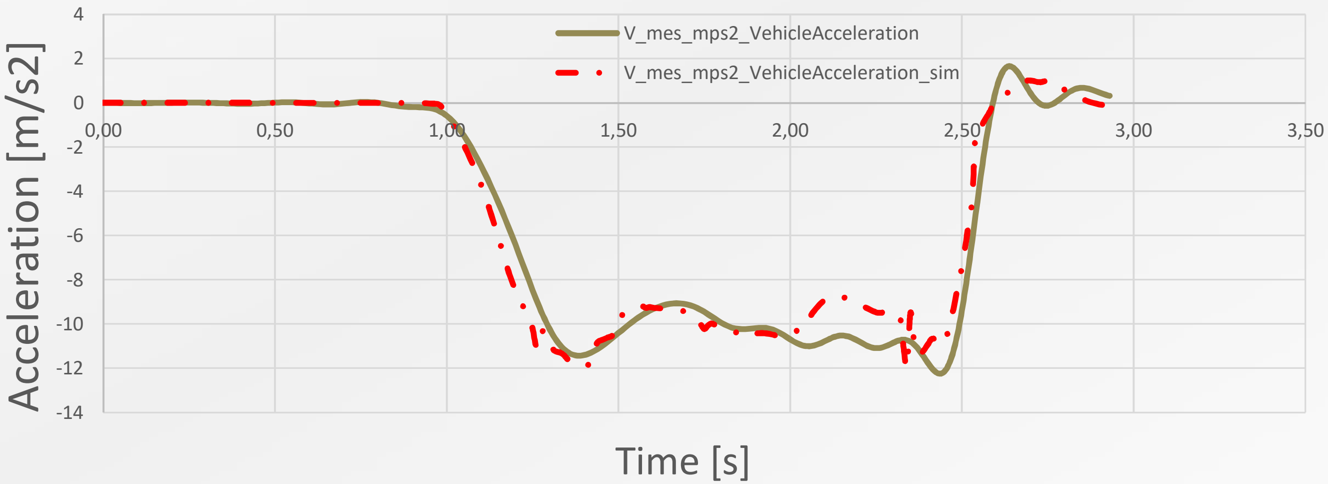
Apply methods with each variables

Step 4

Final correlation rate Compare to requirement

IAPE example

- Curve to curve comparison shows good correlation
- IAPE method to quantify correlation rate



	I	A	P	E	G	C	Correlation Rate
Ponderation	1	1	1	1			
Critere	95,93%	97,45%	99,57%	86,22%	94,79%	92,70%	94%

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UTAC CERAM

Action Plan : AEBS & ALKS virtual test validation & type approval

2018

Test reference despite dispersions for test/simu gaps

Method with gaps values for acceptable gaps

Draft procedure UTAC for AEB virtual test validation

2019, Oct. 31st

Test procedure with OEMs AEB tests

2019, Dec. 31st

Convergence with OEMs

UTAC repetability AEB tests with OEMs vehicles

Work with OEMs :
Target = 3 OEM x 2 véh

UTAC meetings with
- French simu OEM experts
- French TAA
- Euro NCAP & PEARS WGs

UTAC meeting with European Commission

2020, May 4th

Presentation to French automotive industry

2020, May 15th

GRVA IWG AEBS M1-N1 (R152) views sharing and first amendment draft proposal to allow virtual testing as alternative solution to physical tests

2020, Sept. 10th / 11st

GRVA IWG VMAD, ALKS regulation annex 4 amendment proposal to detail conditions for virtual testing acceptability to be provided by OEM

Middle 2021

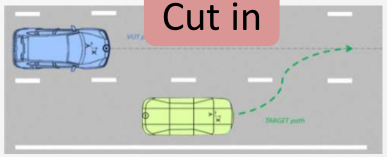
VMAD experts discussion including SG2a activities

Action Plan : AEBS & ALKS virtual test validation & type approval

FR proposal for presentation to GRVA IWGs VMAD

- Virtual test validation method presentation (based on the current slides)
  - Information sharing, experts discussions and contracting parties feedbacks
  - Proposal for next steps to introduce such approach as virtual testing alternative for AEBS M1-N1 with longitudinal application only
  - Proposal for next steps to detail such approach for virtual testing in ALKS audit/assessment annex with longitudinal application only

Cut in



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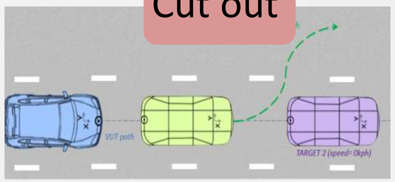
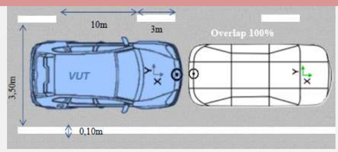
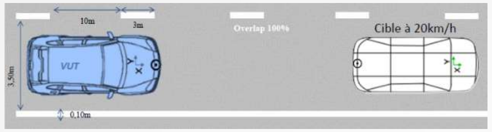


Stationary obstacle/car/VRU



Following & Braking car/PTW



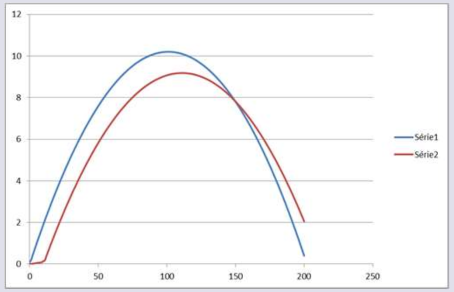
Lane keeping

Objective curves comparison method (IAPE)

- While methods are already known for comparing two scalars, such as error calculation and ratio calculation, there is no well-defined method for comparing curves ➔ The aim here is therefore to define a method which, based on a pair of curves, can produce a single scalar that characterises the correlation quality.

- The first stage of this method is to list the characteristic values we want to compare. Each characteristic value must then be expressed in a mathematical formula from which a single scalar can be extracted. This scalar must be a dimensionless number between 0 and 1, to facilitate expressing it as a percentage (where 1 corresponds to a perfect correlation) ➔ each scalar obtained will be a criterion for the characteristic value.

- UTAC therefore suggests that the following criteria be defined in order to compare the characteristic values (single value or curve as a function of time - IAPE method):
  - I = Appearance of peaks moment criterion (max. & min. – ratio method)
  - A = Amplitude of peaks criterion (max. & min. – ratio method)
  - P = Profile of curve criterion (least-squares average for error at each point)
  - E = Error criterion (integral of error over time)



CORRELATION

I = 90.99%
A = 90.00%
P = 95.11%
E = 82.33%
G = 89.61% (unweighted)
C = 88.63% (unweighted)

Objective curves comparison method (IAPE)

- To conclude, a single score can thus be extracted from these various criteria using one of the following two weighted average calculations (and then converted into a percentage if necessary):
  - G = Geometric weighted mean
  - C = Weighted-average least squares

- Depending on the purpose of the analysis and according to the associated regulatory requirements, Technical service will set the level of representativeness that the manufacturer has to meet for acceptance of the correlation: weighting to be applied, type of average to use and minimum associated percentage.

Objective curves comparison method (IAPE)

Appearance of peaks moment criterion (I)

This criterion is used to compare the max. & min. appearance of peaks moments.

Where Tf_extr is the moment when |f(t)| is maximum.
Where Tg_extr is the moment when |g(t)| is maximum.

The appearance of peaks moment criterion is defined by the following ratio method:

$$I = \frac{\max(0, T_{f\_extr} * T_{g\_extr})}{\max(T_{f\_extr}^2, T_{g\_extr}^2)}$$

The numerator avoids negative values.

Use of the ratio method to calculate error is preferable to the traditional method of differences because of its symmetry characteristic. A reversal of Tf_extr and Tg_extr in no way modifies the result.

Profile of curve criterion (P)

This criterion is used to calculate average error. Curves f(t) and g(t) are defined as a list of points (x, y) and can be written as f(tn) and g(tn), where tn is an abscissa on the nth point of the curve.

At each point, error is calculated as before:

$$erreur_n = 1 - \frac{\max(0, f(t_n) * g(t_n))}{\max(\delta, f(t_n)^2, g(t_n)^2)}$$

δ being a very small value in comparison to 1, to avoid any division by 0.

This error is used to calculate an average using the least-squares method. This method is preferable to the traditional average calculation since it is more sensitive to variations in the criteria.

This profile of curve criterion is thus defined by the following formula:

$$P = 1 - \sqrt{\frac{\sum_n \max(|f(t_n)|, |g(t_n)|) \cdot \left(1 - \frac{\max(0, |f(t_n)| * |g(t_n)|)}{\max(\delta, f(t_n)^2, g(t_n)^2)}\right)^2}{\sum_n \max(|f(t_n)|, |g(t_n)|)}}$$

δ being a very small value in comparison to 1, to avoid any division by 0.

Error at the nth point is therefore weighted by the value of the curve at this point.

Amplitude of peaks criterion (A)

This criterion is used to compare the max. & min. extreme peak amplitudes.

Where f_extr is the f(Tf_extr) function.
Where g_extr is the g(Tg_extr) function.

For the same reasons as above, the amplitude of peaks moment criterion is defined by the following ratio method:

$$A = \frac{\max(0, f_{extr} * g_{extr})}{\max(f_{extr}^2, g_{extr}^2)}$$

Single score average (G & C)

In order to obtain a single score to present the level of correlation between the two values or curves, an average of the criteria can be calculated (as cited above).

Two methods can be used to reach this average:

- Weighted geometric mean (G): traditional average of criteria weighted by a coefficient called Wn.

$$G = \frac{\sum_n (W_n \cdot crit_n)}{\sum_n W_n}$$

- Weighted-average least squares (C): average more sensitive to the variations in the criteria, always weighted by a coefficient called Wn.

$$C = 1 - \sqrt{\frac{\sum_n (W_n \cdot (1 - crit_n)^2)}{\sum_n W_n}}$$

Error criterion (E)

This criterion is used to calculate error as follows:

$$erreur(t) = \frac{f(t) - g(t)}{\max(|f(t)|, |g(t)|)}$$

The criterion associated with this error can be calculated in two different ways:

- **Absolute integral (E1):** here, the absolute error value is integrated over an interval of time. The integral is then divided by the length of the interval to obtain a dimensionless value. We thus have a value that remains positive but is not necessarily between 0 and 1. The exp(-x) function is used purely to bring this value to between 0 and 1.

  In this case, the least squares method gives us:

$$E1 = \exp\left(-\frac{1}{t_{max} - t_{min}} \cdot \int_{t_{min}}^{t_{max}} \left|\frac{f(t) - g(t)}{\max(|f(t)|, |g(t)|)}\right| dt\right)$$

- **Absolute of the integral (E2):** here, the absolute value is taken directly from the integral of error. The integral is then divided by the length of the interval to obtain a dimensionless value. We thus have a value that remains positive but is not necessarily between 0 and 1. The exp(-x) function is used purely to bring this value to between 0 and 1.

  In this case, the least squares method gives us:

$$E2 = \exp\left(-\frac{1}{t_{max} - t_{min}} \cdot \left|\int_{t_{min}}^{t_{max}} \left(\frac{f(t) - g(t)}{\max(|f(t)|, |g(t)|)}\right) dt\right|\right)$$

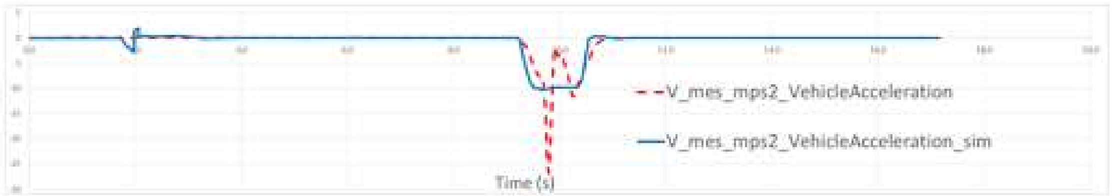
The error criterion is therefore finally defined by the least-squares average as follows:

$$E = 1 - \sqrt{\frac{(1 - E1)^2 + (1 - E2)^2}{2}}$$

Annex I – Focus on IAPE methodlogy

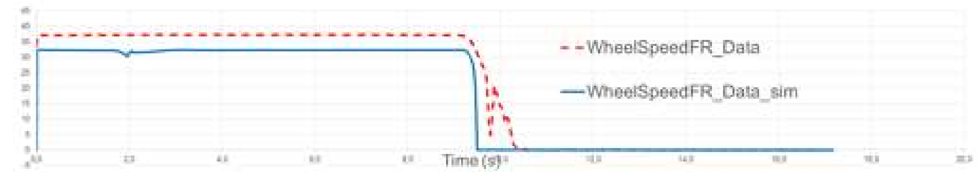
UTAC CERAM

Objective curves comparison method (IAPE)



	I	A	P	E	G	C	Taux de corrélation
Critere	98,57%	38,77%	99,65%	87,89%	75,44%	63,97%	70%

	I	A	P	E	G	C	Taux de corrélation
Critere	78%	100%	100%	100%	95%	89%	92%



	I	A	P	E	G	C	Taux de corrélation
Critere	76%	87%	100%	73%	86%	82%	84%