ADAS & Autonomous Vehicle Technology Expo Stuttgart June 15th 2023

New paradigm for Autonomous Vehicle: Artificial Intelligence – based prudence assessment

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Facts

The development of Autonomous Vehicle which was originally scheduled to be completed in 2020 is taking longer and longer with more and more restriction of the Operational Design Domain (ODD). Yet billions of dollars are invested and many, many brilliant minds are at work.

Quote

*"Autonomous systems are not as capable as people because their "**perception and prediction algorithms are not as good as how a human brain processes and decides**,"* said Chris Borroni-Bird, an independent consultant who previously led advanced-vehicle programs at GM and Waymo.

Potential reason for this failure

Teams are brilliant, no doubt, and then if they fail, it means that they use a wrong paradigm. We call paradigm the way that the question of Autonomous Driving is translated into engineering questions. A wrong paradigm may lead to questions with no answer or too complicated answers. Complicated to achieve and complicated to validate.

Most Frequent Paradigm in Autonomous Vehicle Development

Paradigm

1- Split open world situations in N use-cases (e.g. N going from 100 to 1000)

2- In every use case, specify expected behavior

3- Develop the robot, use-case by use case

4 - Validate

Technical Questions

1- What is needed information to recognize the current use-case ?
2 – What is the expected behavior in every use-case (explicitly desbribed or represented by a database of examples for learning-based technical solutions) ?
3 - What is needed information to measure error between actual behavior and expected behavior ?
4 – What is the system of acquisition that can bring all needed information ? Perception, V2X, other …

Result

Number of information acquisition systems (perception, V2X, …) tends to infinite with a cost that is not compliant with personal vehicle market. Information acquisition system is the adjustment variable in this paradigm.
This approach doesn't take into account the fact that we may NOT KNOW some context characteriscics: knowing everything at any time is not possible in the open world, by definition of open world (not a controlled enviroment).
There are at least 2^N junctions between use-cases that are impossible to check.
There is no explicit measurement of road safety, replaced with a number of billion km without accident
failure at the wall of complexity (in the mathematical sense)

Complexity is much higher than Automotive Indutry thought

Sensors complexity
Let's take the case of perception with a regular HD camera:
. Three 8 bits color (Red Green Blue) images = 24 bits
Every pixel can take 2^{24} different values. This number is a little higher than 16 000 000.
There are 2 000 000 pixels.
Number of different possible images on such a sensor is higher than $16\,000\,000^{\,2\,000\,000}$
According to physicists, this number is bigger than number of atoms in the galaxy.

How to validate a system using such sensors ? Big database ? **NO**

Open world complexity
Between two use cases that you have thought of, **there is at least one other use case**

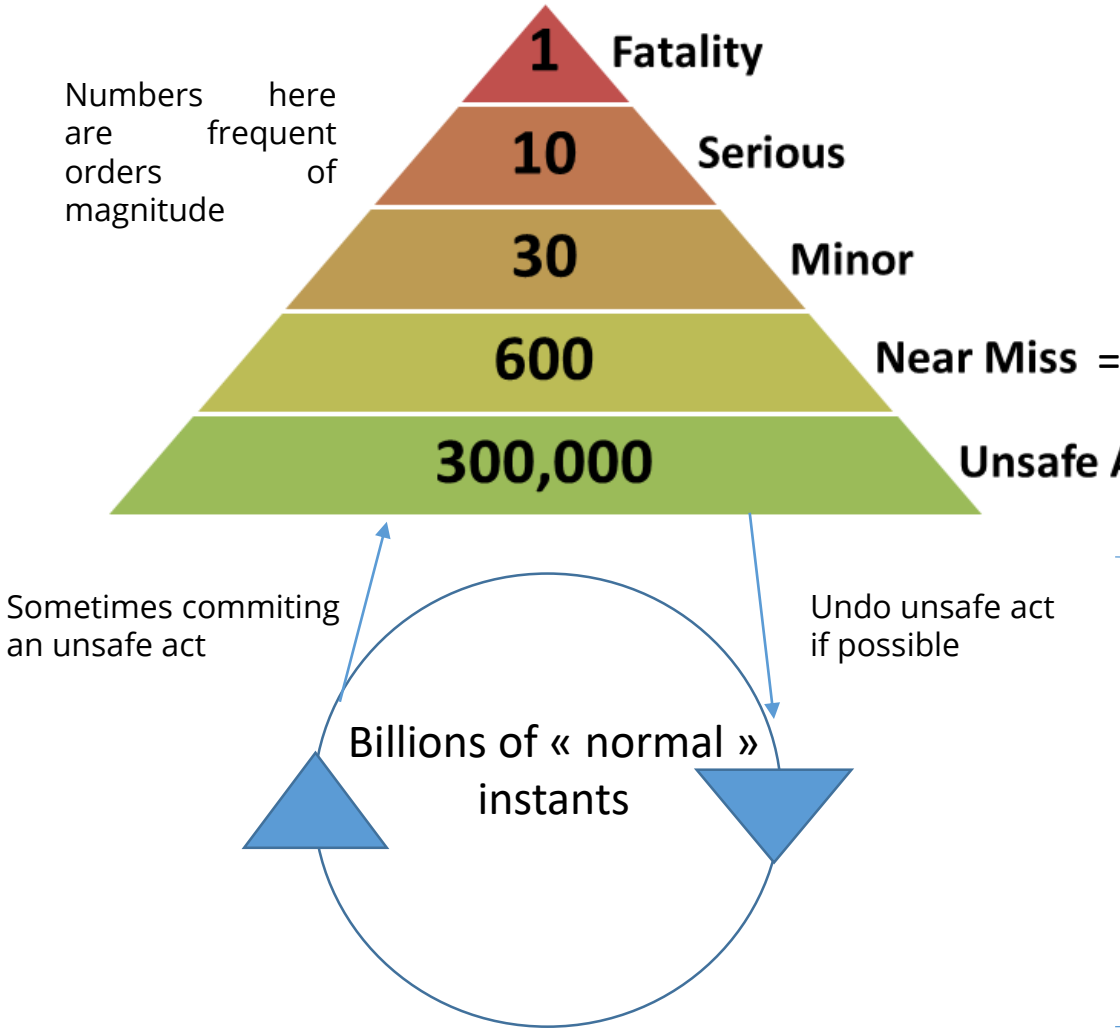
How to validate a system in the open world ? Big database ? **NO**

Road Safety Complexity
In OECD, human drivers have **1 accident in average every 100 000 km, and there are 3 fatalities every billion km**. At the local scale (here and now) probability of accident is close to zero.

How to validate a system in the open world ? Big database ? **NO**

How to define a new paradigm : Theory of risk

Theory of Risk, by Frank E. Bird : triangle of risk for driving task



Near Miss = emergency situation, needs reaction to avoid or mitigate accident (AEB etc)

Unsafe Act = entering triangle of risk

15 years of collaborative research programs :

Specification of a way to estimate distance to unsafe act.

We called this distance « **prudence** ».

Definition of « good driving behavior »: trying not to enter triangle of risk is possible. Proceed to « undo unsafe act » if needed if possible

What is prudence ? You all already know it

I came to visit you. I crossed every stop sign without stopping the vehicle, and I had no accident. **I declare then that my driving behavior was safe** (no accident).

You answer me « no it was not a safe behavior » although it doesn't appear in the database (no accident. BTW, should I push the « LEARN » button of a deep learning machine ?)

And why do you answer me NO ? Because you **KNOW** it. **Prudence is a knowledge** learned at school, in driving schools, etc. And also learned « in the long term » while driving. This human notion is not as measurable as criticallity (for instance) that may be measured with time to collision, and probability of trajectories interception.

Are there experts that assess prudence in a **repeatable** and **quantitative** way ? **YES**
. Road safety departments of Governments
. Police of the road
. Driving schools instructors
. Drivers of collective transport vehicles (school buses, ...)

Dictionnary (prudence): taking into account in your behavior that you don't know everything on context (e.g. surrounding context), and that it is impossible to predict every consequence of your acts.

During 15 years, we have:

. Extracted this knowledge, from more than 100 experts, in 19 countries
. Validated it with the panel of experts
. Integrated it into a composite AI (core techs are fuzzy logic and possibility theory)
. Validated it on aftermarket applications for fleets (worldwide, including in India):
. Validated it on a prototype of Predictive/Contextual ACC with STELLANTIS Group

New paradigm using prudence: vehicle behavior becomes the adjustment variable

New Paradigm

1 – Assessing prudence, with the actual set of information capture system

2 – Ask Automation Engineers to compute which behavior can keep prudence at an acceptable level (or keep risk at an acceptable level, where risk is « lack of prudence », according to our presentation of Frank E Bird theory. We call the acceptable prudence « prudence target » and the acceptable risk (risk =1 – prudence) the « risk target.

Automation Engineers only have **ONE variable to control**, and **ONE setpoint value**, for every use-cases.

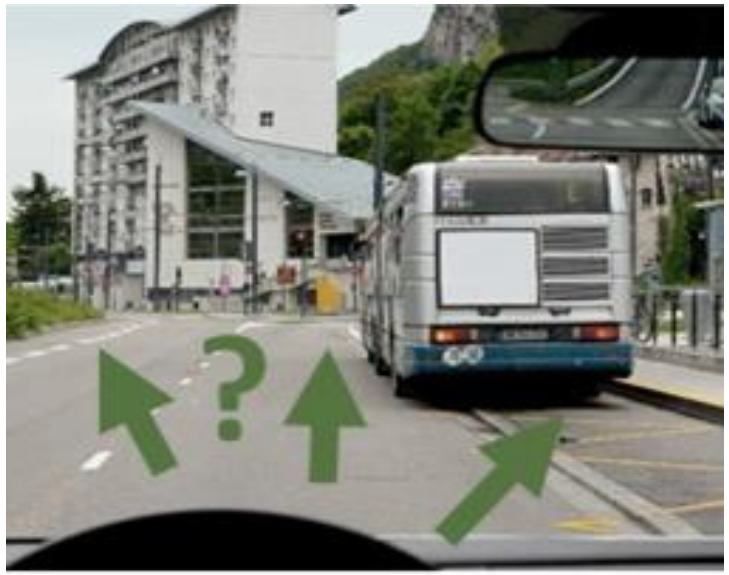
Modification of the setpoint value changes global behavior of the vehicle (sportiveness or aggressiveness): ONE parameter is easier to tune than hundreds of control laws maths coefficients or millions of deep learning parameters.

Prudence assessement is put on a scale 0-100% which is a **continuum**.

This doesn't solve « everything » on Autonomous Vehicle project, but **it divides by 100 to 1000 complexity** of the solution.

NB: this « **knowledge-based system** » needs « learning » to auto-calibrate parameters (2 wheelers, different cars categories, heavy trucks): it involves then **Machine learning, Deep learning**, and **Neural Gas**. Of course it also uses physics as it is a vehicle by the way.
Architecture of the composite AI system is described in the paper we quote in reference [Yah2022]

Example of a complex use-case



. **If you know what is behind the bus** (*), **and if there is nothing**, it is possible not to slow down, go straight ahead, and still stay PRUDENT
(*) e.g. cameras on the infrastructure + V2X, or frontal cam of the bus + V2X

. **If you do not know what is behind the bus** it is necessary to slow down an may be slightly keep left, in order to stay PRUDENT (because a pedestrian may appear from behind at the last moment)

Vehicle Behavior is no longer a prerequisit setpoint notion, but **a consequence of PRUDENCE target and equipment set**. You can have **different** PRUDENT Autonomous Vehicles with **different** behaviors that will depend on their equipment set (and start with **cheap** equipment). Also, in real time, **behavior of an Autonomous Vehicle will change to stay PRUDENT** if some information is temporary missing : a completely new flexible way of thinking.

Example of application: longitudinal control

Composite physics-informed AI:

fuzzy sets, possibility theory deep learning, reinforcement learning, neural gas, physics, applied maths

DATA AGGREGATION IN REAL TIME IN A CENTRALIZED AI

. digital map read by Electronic Horizon

. detection of surround objects from camera/lidar/…

. interdistance measured by front radar/lidar/cam

. Driver Monitoring System detections

. measurement of dynamic and kinematic elements (accelerations, vehicle speed, yaw rate, etc.)

. signal from the blinker

. V2X hazard warning

(+ grip of the road, visibility, etc)

NEXYAD AI SafetyNex

Prudence and lack of prudence values (0-100)
20 times per second

Lack of prudence **alerts** (events)

Prudent **recommended speed** (RS)

Distance where RS should be applied

Acceleration/Deceleration that should b applied to be prudent **20 times per seco**

Tuning parameters for OEM

. Max accepted Lack of prudence (risk target)

. Comfort: max accel, max decel, max jerk

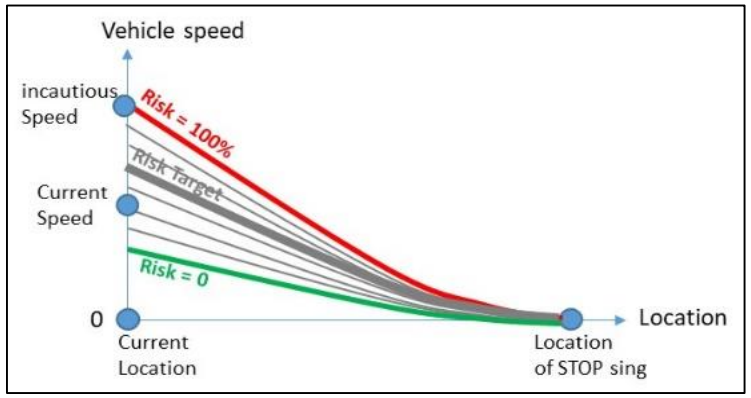
In blue mandatory inputs for Minimum Viable Product

(*) Lack of prudence is called ‘risk’

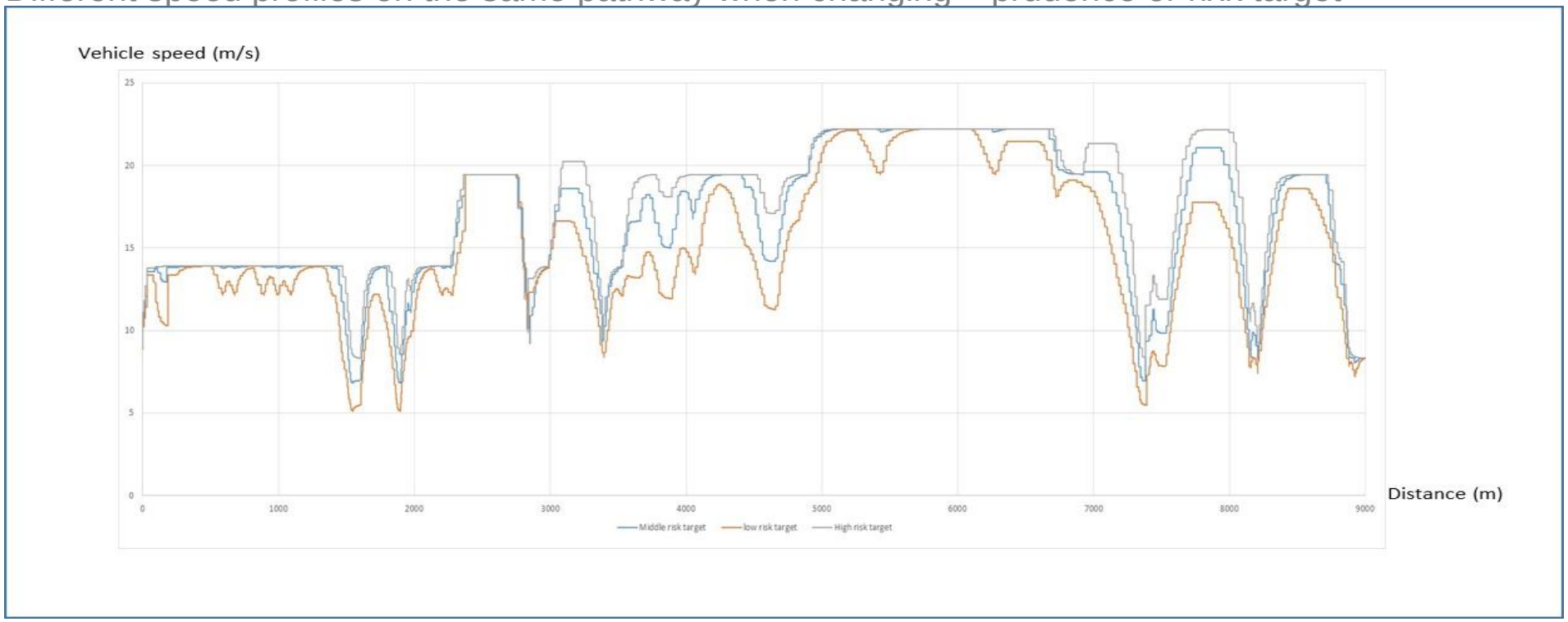
Example of implementation to pilot a predictive ACC for STELLANTIS Group

STELLANTIS Peugeot 308 Labcar Predictive ACC

1. Prudence assessment (20 times per second): 3% of a regular ECU
2. If prudence is too low then slow down, else, accelerate to speed limit



Different speed profiles on the same pathway when changing « prudence or rixk target »



Conclusion

A new paradigm than simplifies the question, then helps find solutions

Automotive Engineers have **many ideas of applications** since they have this new tool in hands: e.g. « in use monitoring of existing Autonomous Vehicle »

It may be a way to **enlarge ODDs** and **shorten Autonomous Vehicle development times**

Of course, it has many other applications: e.g. answering the tricky request of **euroNCAP**:
« paste the appropriate speed in any situation »
« appripriate » doesn't have a clear definition does it ?

We propose to define « **appropriate speed** » as « **prudent speed** ».
We assess prudence, it is easy to assess prudent speed.

Demos available in the Paris area on a real car in real complex streets around RENAULT technocenter in Guyancourt:

Thank you for your time

Annex: how it works (for AI and mathematics experts)

Main points will be described in the written paper version in a synthetic summary.

AI and Maths aspect of our composite AI are detailed in:
Gerard Yahiaoui & Pierre Da Silva Dias, Hybrid Physics-Informed Artificial Intelligence for Driving Assistance : Application to Preventive Automated Cruise Control, SIA Congress “AI and new mobility”/ “IA pour les nouvelles mobilités”, Sept 2022

References on AI methods that we use and on theory of risk are in this scientific publication and will be listed in written paper.