RENAULT intellitech

INDUSTRY / R&D

EMERGENCY DETECTION FOR AN AUTOMATIC BRAKING ASSIST

Benchmark vs. Random Forests, Boosted Trees & Neural Networks

Use Case 2021/11 (v1.3) • www.xtractis.ai

PROBLEM DEFINITION

PROBLEM

How to automatically, efficiently and transparently diagnose driving situations to activate the emergency braking, only from the car recordings without camera, radar, or lidar?

GOALS & BENEFITS

☑ Identify the car parameters involved in the driving situation diagnosis and enhance technical knowledge by helping engineers understand the causal relationships between specific parameters, their combination, and the occurrence of an emergency.

☑ Approach the perfect model: the slightest mistake can be fatal. Help engineers design reliable intelligible autonomous vehicles that assist the driver efficiently according to their driving style. *Intelligible* means that the internal decision logic of the decision system is explicit.

☑ Enforce the use of stable and transparent models audited by the domain expert and certified by the regulator before embedding them in the vehicle.

☑ Challenge XTRACTIS to find better models than those we initially crafted "by hand" and far quicker!®

REFERENCE DATA

▶ **Observations**: 108 driving trials resulting in over 1,200,000 driving situations, with and without emergency braking sequences, from experimental R&D campaigns conducted by RENAULT, on test track or open road: 52 trials (including 508,696 situations) for Training/Validation/Test and 56 trials (including 732,000 situations) for External Test.
Source: RENAULT Patent #WO02057123 (P. Romieu, C. Lorel, Z. Zalila, J. Benizri 2001)

▶ **Predictive Variables**: 17 Potential Predictors characterize each driving situation, such as driver gender, and car sensor recordings [throttle angle, membrane stroke, pedal stroke, longitudinal deceleration, rod effort, right rear pressure, ...].

▶ **Variable to Predict**: Diagnosis of the Driving Situation [STANDARD / EMERGENCY] to activate or not the Emergency Brake Assist (EBA).

MODEL TYPE: Regression | Multinomial Classification | **Binomial Classification** | Scoring

XTRACTIS SOLUTION

PROCESS

Reference Data	INDUCTION	XTRACTIS Top-Model	New Cases	DEDUCTION	Automated Decision (activate EBA or not)
Driving Situations			Driving Situation		STANDARD / EMERGENCY

SOFTWARE ROBOTS: XTRACTIS® GENERATE | XTRACTIS® PREDICT | + PREDICTion Report (for offline explainability)

RESULTS

☑ **Intelligible Predictive Model**: Decision system composed of 25 unchained gradual rules, each rule using some of the 12 variables that XTRACTIS identified as predictors.

☑ **Robust Predictive Model**: Very good performance on External Test.

☑ **Operational Efficient System**: Real-time predictions up to 70,000 decisions/s., offline or online (API).

TOP-MODEL INDUCTION

INDUCTION PARAMETERS

We launch 1,500 inductive reasoning strategies on the same single Training (70%)/Validation (15%)/ Test (15%) partition of the reference dataset. Each strategy thus generates one unitary model called **Individual Virtual Expert** (IVE).

Among the 1,500 induced models, the top-IVE is the one that has the best predictive performance, close to its descriptive performance, and with the fewer predictors and rules (12 predictors shared by 25 rules).

Total number of induced unitary models	Criterion for the induction optimization	Validation criterion for the top-model selection	Duration of the process (Induction Power FP64)
1,500 IVE	F_1-Score	F_1-Score	~18 hours (24 Tflops)

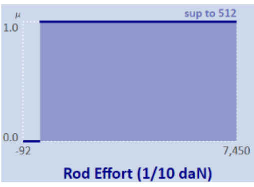
STRUCTURE

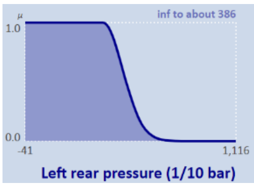
→ Intelligibility

The top-IVE model combines the 12 predictors, automatically selected by XTRACTIS into 25 rules. The Structure Report reveals all the internal logic of the decision system and ensures that the model is understandable by the human expert. It is a *white-box* model that can be audited by the domain expert and certified before deployment to end-users.

PREDICTORS

- 11 vehicle data + driver's gender (out of 17)
- Ranked by impact significance
  (3 strong, 6 medium & 3 weak signals):
  #1 Longitudinal deceleration
  #2 Rod Effort
  #3 … #12
- Labeled by fuzzy and binary classes and one nominal class for the gender
  Examples: **binary interval** "sup. to 512";
  fuzzy interval "inf. to about 386"





RULES

- 25 connective fuzzy rules without chaining (aggregated into 2 disjunctive fuzzy rules)
- 2 to 6 predictors by rule (on average, 3.5 predictors per rule)
- Example: **fuzzy rule R20** uses 4 predictors, and concludes "EMERGENCY". 24 other fuzzy rules complete this model.

IF	Longitudinal deceleration (1/100 m/s2)	IS	sup. to about 62
AND	Rod Effort (1/10 daN)	IS	sup. to 512
AND	Left rear pressure (1/10 bar)	IS	inf. to about 386
AND	Longitudinal speed (1/10 km/h)	IS	sup. to about 826
THEN	Driving Situation	IS	EMERGENCY

PERFORMANCE

→ Robustness

The top-IVE performances, measured in Training/Validation/Test, then in External Test on reference data, guarantee the model's predictive and real performances.

Performance	DESCRIPTIVE	PREDICTIVE	REAL	REAL
Dataset	70% Training	15% Validation	15% Test	External Test
F_1-Score	99.04%	99.04%	98.85%	96.28%
Classification Error	0.09%	0.09%	0.11%	0.45%

→ Xtractis Top-Model: Intelligible <u>AND</u> Very Good Predictive Capacity

EXPLAINED PREDICTIONS FOR 3 CASES FROM THE EXTERNAL TEST DATASET

CASE (not used in Training/Validation) — **DEDUCTIVE INFERENCE OF RULES** — **AUTOMATED DECISION**

SITUATION #Janickfrein68 78.01s (actual value = EMERGENCY)

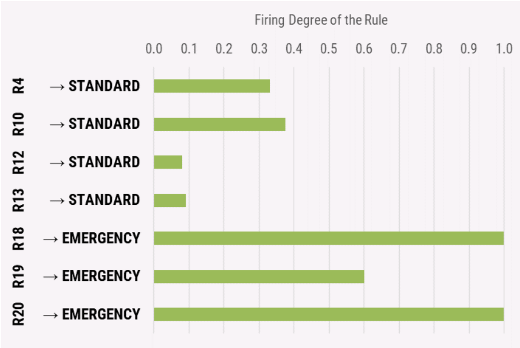
Membrane Stroke (1/100 mm)_IT	1,534
Longitudinal deceleration (1/100m/s2)	244
Rod Effort (1/10 daN)	882
Left rear pressure (1/10 bar)	256
Master Cylinder 1 pressure (1/10 bar)	595
Master Cylinder 2 pressure (1/10 bar)	M.V.*
Manifold pressure (mbar)	M.V.*
Pressure in mastervac (mbar)	M.V.*
Engine speed	3,395
Longitudinal speed (1/10 km/h)	897
Membrane speed (mm/s)_IT	123
Driver Gender	man

Real Time

For this driving situation, 7 rules are triggered:

R18 and **R20** at 1.000, **R19** at 0.600, **R10** at 0.375, **R4** at 0.331, **R13** at 0.091 and **R12** at 0.081

All other 18 rules are not activated.



NUMBER OF TRIGGERED RULES
7 / 25

FUZZY PREDICTION
{ EMERGENCY|1.000, STANDARD|0.375 }

FINAL PREDICTION
{ EMERGENCY }

The systems delivers a correct diagnosis of the driving situation compared to the actual situation in the experiment:

EBA activation

SITUATION #Jean-Pierre frein78 99.94s (actual value = STANDARD)

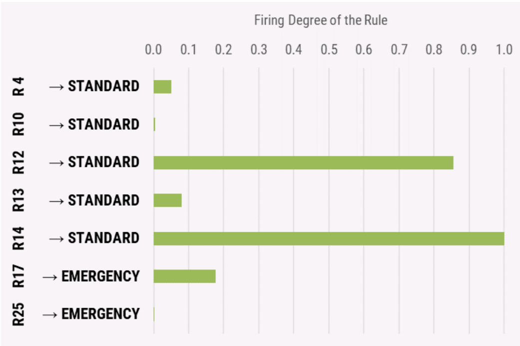
Membrane Stroke (1/100 mm)_IT	**273**
Longitudinal deceleration (1/100m/s2)	**67**
Rod Effort (1/10 daN)	**21**
Left rear pressure (1/10 bar)	**3**
Master Cylinder 1 pressure (1/10 bar)	**0**
Master Cylinder 2 pressure (1/10 bar)	M.V.*
Manifold pressure (mbar)	M.V.*
Pressure in mastervac (mbar)	M.V.*
Engine speed	**694**
Longitudinal speed (1/10 km/h)	**196**
Membrane speed (mm/s)_IT	**-51**
Driver Gender	man

Real Time

For this driving situation, 7 rules are triggered:

R14 at 1.000, **R12** at 0.856, **R17** at 0.176 **R13** at 0.080, **R4** at 0.051, **R10** at 0.004 and **R25** at 0.003

All other 18 rules are not activated.



NUMBER OF TRIGGERED RULES
7 / 25

FUZZY PREDICTION
{ STANDARD|1.000 , EMERGENCY|0.176 }

FINAL PREDICTION
{ STANDARD }

The systems delivers a correct diagnosis of the driving situation compared to the actual situation in the experiment:

No EBA activation

SITUATION # Marie-F.frein150 114.85s (actual value = STANDARD)

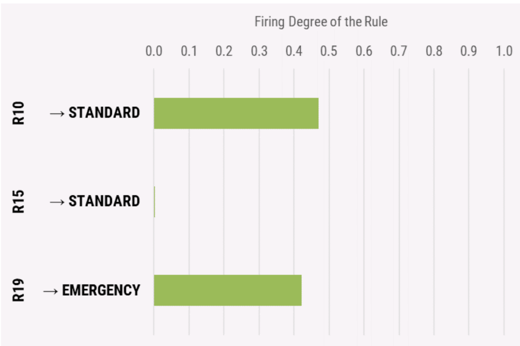
Membrane Stroke (1/100 mm)_IT	2,398
Longitudinal deceleration (1/100m/s2)	220
Rod Effort (1/10 daN)	993
Left rear pressure (1/10 bar)	895
Master Cylinder 1 pressure (1/10 bar)	915
Master Cylinder 2 pressure (1/10 bar)	M.V.*
Manifold pressure (mbar)	M.V.*
Pressure in mastervac (mbar)	M.V.*
Engine speed	694
Longitudinal speed (1/10 km/h)	12
Membrane speed (mm/s)_IT	-7
Driver Gender	woman

Real Time

For this driving situation, 3 rules are triggered:

R10 at 0.470, **R19** at 0.422, and **R15** at 0.003

All other 22 rules are not activated.



NUMBER OF TRIGGERED RULES
3 / 25

FUZZY PREDICTION
{ STANDARD|0.470, EMERGENCY|0.422 }

FINAL PREDICTION
{ STANDARD }

The systems delivers a correct diagnosis of the driving situation despite hesitation (conflicting rules with close degrees):

No EBA activation

During this recording, the system in fact just switched from an "emergency" to a "standard" state, no longer requiring additional EBA. It is an evolutionary temporal process, where we gradually pass from one state to another. However, the system should have made this change of state 18 records ago, i.e. 0.06s earlier.

**M.V. = Missing Values. These parameters were not measured during the External Test campaign.*

TOP-IVE BENCHMARK

	XTRACTIS	RANDOM FOREST	BOOSTED TREES	NEURAL NETWORK
MODELS RELEASE	2021/11	2021/11	2021/11	2021/11
ALGO VERSION	XTRACTIS GENERATE 11.3.40047	Python 3.6 LightGBM 2.2.2	Python 3.6 LightGBM 2.2.2	Python 3.6 TensorFlow 1.7, Keras 2.1.4
CROSS-VALIDATION TECHNIQUE	1-Split Validation: 70% Training / 15% Validation / 15% Test			
NUMBER OF EXPLORED STRATEGIES	1,500 induction strategies	1,500 ML strategies	1,500 ML strategies	1,500 ML strategies
	All IVE models are optimized according to their validation F_1-Score. The top-IVE are selected according to their validation F_1-Score while checking that it remains close to their training F_1-Score			
NUMBER OF GENERATED MODELS	1,500 IVE	1,500 IVE	1,500 IVE	1,500 IVE

TOP-IVE STRUCTURE

	XTRACTIS	RANDOM FOREST	BOOSTED TREES	NEURAL NETWORK
NUMBER OF PREDICTORS (out of 17 potential predictors)	12	17	17	17
DECISION STRUCTURE	System with 25 unchained fuzzy rules (or 2 disjunctive fuzzy rules)	12 trees; 851 binary rules	169 chained trees; 7,415 binary rules	4 hidden layers; 88 hidden nodes
MODEL INTELLIGIBILITY (& DECISION EXPLAINABILITY)	+++ 3.5 predictors per rule on average; only a few rules are triggered at a time.	−−− Lots of predictors and rules	−−− Tree #N corrects the error of the N-1 previous trees	−−− Unintelligible synthetic variables

TOP-IVE REAL PERFORMANCE BY POINTS (intrinsic quality of the model)

	XTRACTIS	RANDOM FOREST	BOOSTED TREES	NEURAL NETWORK
Classification Error	0.45%	0.66%	0.67%	1.27%
Sensitivity	94.37%	91.12%	92.55%	84.78%
Specificity	99.89%	99.89%	99.77%	99.64%
PPV	98.26%	98.04%	96.41%	94.01%
NPV	99.63%	99.42%	99.51%	99.00%
F_1-Score	96.28%	94.45%	94.44%	89.16%
Refusals	0.05%	N/A	N/A	N/A
MODEL ROBUSTNESS BY POINTS	#1	#2	#2	#4

As the system is dynamic, the performances by points do not secure against a possible instability in decision-making. If, for example, during an emergency braking sequence, the model alternately concludes EMERGENCY and STANDARD over successive time lapses, this would cause flaws in the system. For this reason, we need to evaluate the top-IVE's performance on driving sequences by trials.

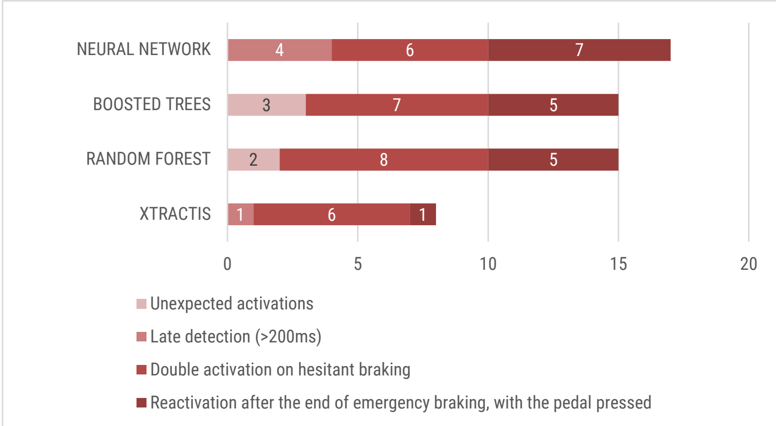
TOP-IVE REAL PERFORMANCE BY TRIALS (decision stability of the model)

	XTRACTIS	RANDOM FOREST	BOOSTED TREES	NEURAL NETWORK
Classification Error	0.00%	0.88%	1.33%	0.00%
Sensitivity	100.00%	100.00%	100.00%	100.00%
Specificity	100.00%	98.82%	98.23%	100.00%
PPV	100.00%	96.55%	94.92%	100.00%
NPV	100.00%	100.00%	100.00%	100.00%
F_1-Score	100.00%	98.25%	97.39%	100.00%
Refusals	0.00%	N/A	N/A	N/A
MODEL ROBUSTNESS BY TRIALS	#1	#2	#3	#1

Problematic Cases (from External Test trials)

Each trial consists of driving data that include at least one normal situation and sometimes an emergency. We count the emergency braking sequences detected, and the delay between detection and actual emergency. If the model does not detect an emergency, we count an unfortunate non-triggering. Alternatively, for standard driving or braking sequences, if the model detects an emergency wrongly, we count an unexpected activation. Besides, we notice 2 other types of problematic cases related to specific driving situations:

1. Hesitant braking: the driver hesitates and brakes in 2 steps. If the system disconnects between the 2 steps, we count a double activation.
2. Reactivation after the end of emergency braking, with the pedal pressed: the driver keeps pressing the brake pedal after the vehicle has stopped, sometimes placing the model in a new emergency situation while the vehicle is stationary.

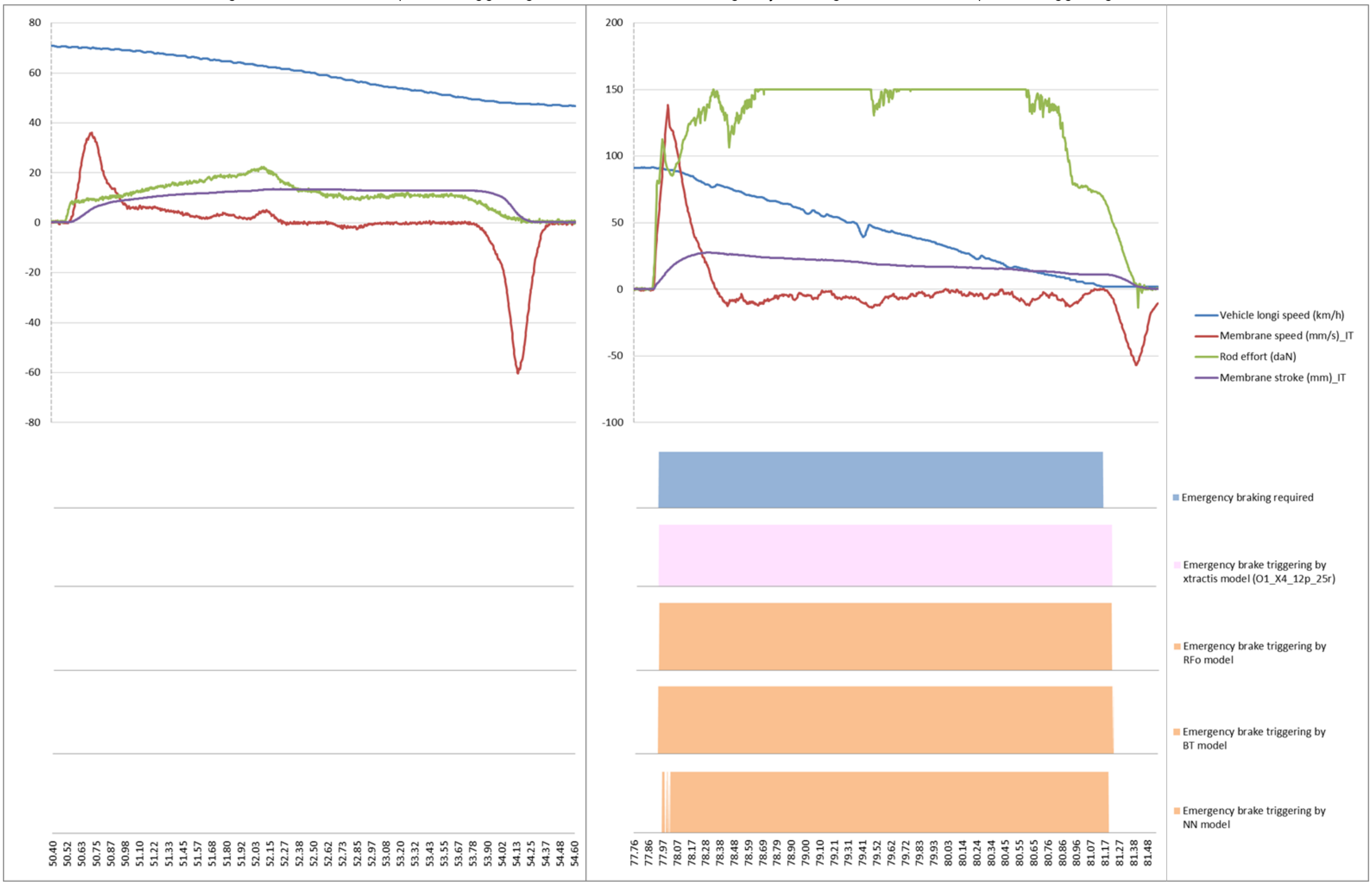


Examples of Right and Wrong Diagnoses (from External Test trials)

The following graphs show driving situations over 4-5 seconds, either with a standard braking sequence or requiring emergency braking (blue band). Wrong diagnoses are taken from the problematic cases identified above.

1/ Situations with correct diagnosis from the models

Trial #68 – Standard braking situation with no expected triggering **Trial #68** – Emergency braking situation with expected triggering

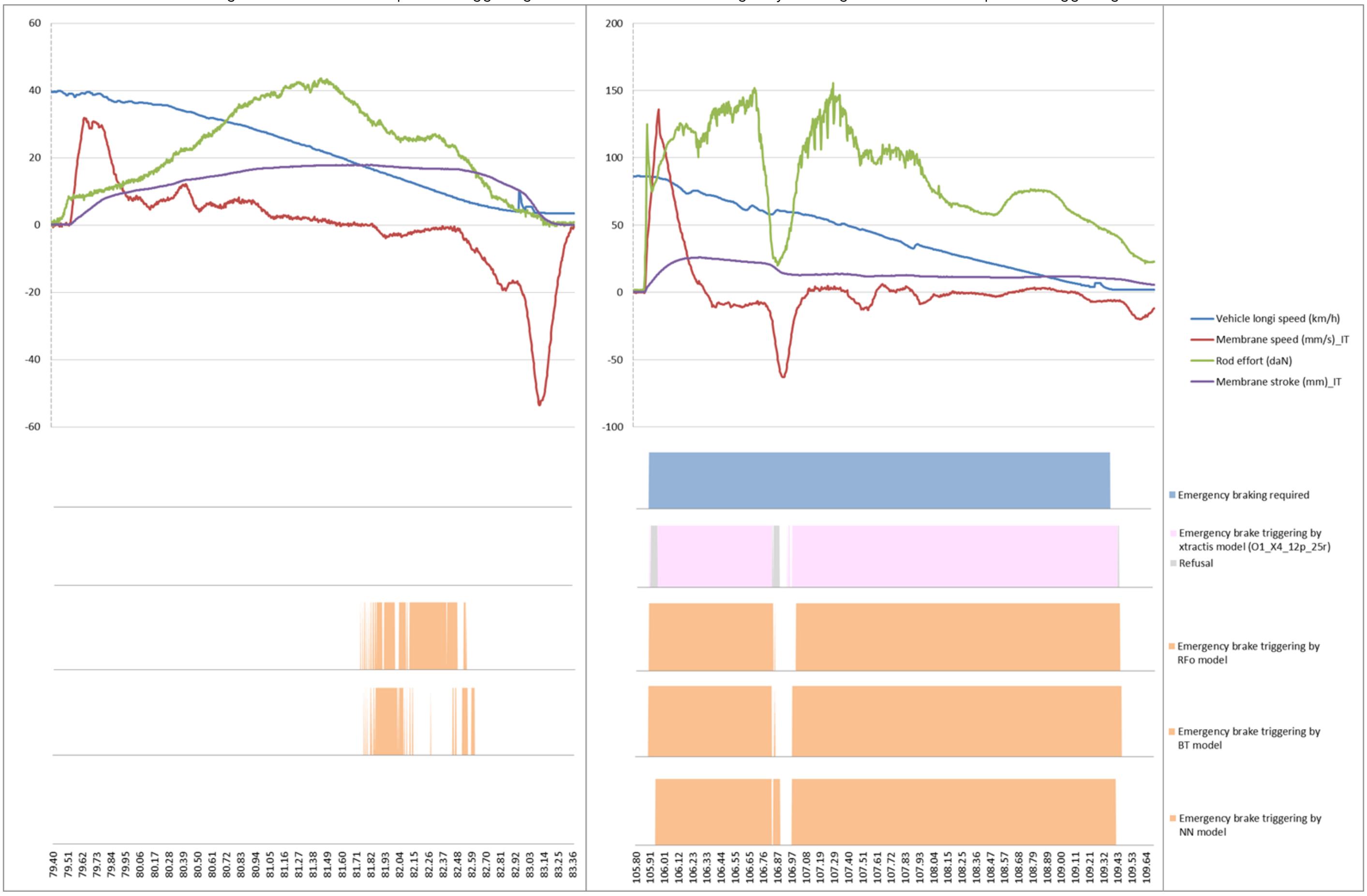


The 4 decisional systems correctly diagnose standard braking, as there is no untimely activation of the EBA. When emergency braking is requested, the NN top-IVE hesitates at the beginning of the sequence, while the XTRACTIS, RFo, and BT top-IVE react perfectly.

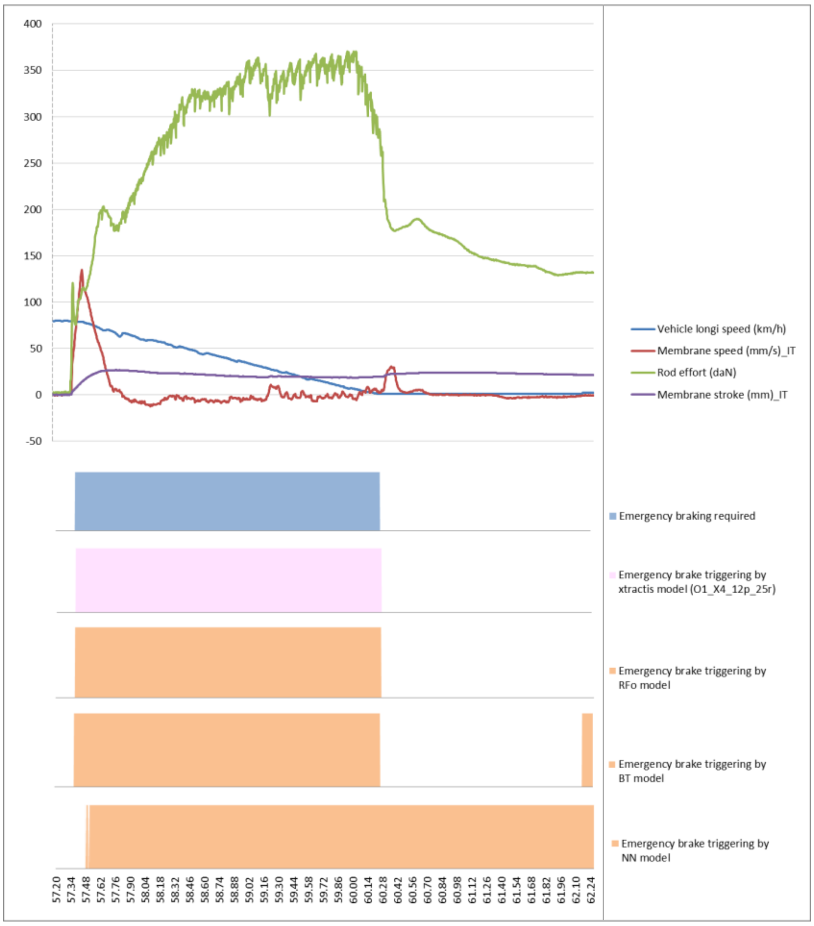
2/ Situations with problematic diagnosis from the models

Trial #71 – Standard braking situation with no expected triggering

Trial #103 – Emergency braking situation with expected triggering



Trial #93 – Reactivation after end of emergency braking with pedal pressed



During Trial #71, standard braking is well diagnosed by the XTRACTIS and NN top-IVE, while the RFo and BT top-IVE unexpectedly activate EBA.

During Trial #103, when the driver stops braking for a short time (dip in the green curve) and then brakes again, the 4 decisional systems react poorly and lead to the EBA disconnection. The disconnection is more prolonged for the RFo and BT models.

During Trial #93, when the driver continues to brake whereas there is no more emergency, the XTRACTIS and RFo models react perfectly by disconnecting EBA. The BT model also triggers deactivation but decides to reactivate EBA after 2 seconds without any need. The NN model does not disconnect EBA at all.

XTRACTIS vs. Classic Fuzzy Expert Systems

Data from this study was originally used in 1999 to help develop "by hand" a decision support system based on fuzzy rules: an auto-adaptive emergency braking assistance system had been invented by Z. Zalila & INTELLITECH for RENAULT in early 2000. It was subsequently patented [WO02057123] (2001) by RENAULT.

This system was designed using the "traditional" fuzzy logic approach, i.e., the manual design of the fuzzy decision rules, reproducing the human expertise, thanks to our expertise as drivers.

It is, therefore, interesting to compare the two approaches, their main features, and their results. Even if both are fuzzy logic-based approaches, leading to intelligible models (thus auditable and certifiable), we highlight the limitations of traditional Fuzzy Symbolic AI compared to the XTRACTIS Augmented Fuzzy Symbolic AI.

And even if the XTRACTIS top-IVE is perfectible by injecting new data, for example, by merging with data from new sensors, to eliminate the identified problematic cases and further improve its performances, we can affirm that XTRACTIS has met the challenge!

	Classic Fuzzy Expert System	XTRACTIS System
Design Approach	Human induction	Automatic induction
Design Time	24 man months	Max. 1 day with a 24 Tflops HPC server
Number of Rules	25 fuzzy rules for short time diagnosis + 2 fuzzy rules for braking behavior + 1 Fuzzy Relation of order 3	25 fuzzy rules
Number of Predictors	4 (cognitive limitation of the human modeler)	12 (selected automatically)
Performance	Descriptive model only: incremental performance by trial/error	Robust predictive model: systematic estimation of descriptive and predictive performance by cross-validation

Benefits of XTRACTIS AI vs. classic Fuzzy AI:

- **Overcoming human cognitive limitations: more parameters and driving situations could be taken into account.**
- **Much higher performances: greater reliability of the decision-making strategy.**
- **Much faster and less expensive design.**

More Use Cases:
xtractis.ai/use-cases/