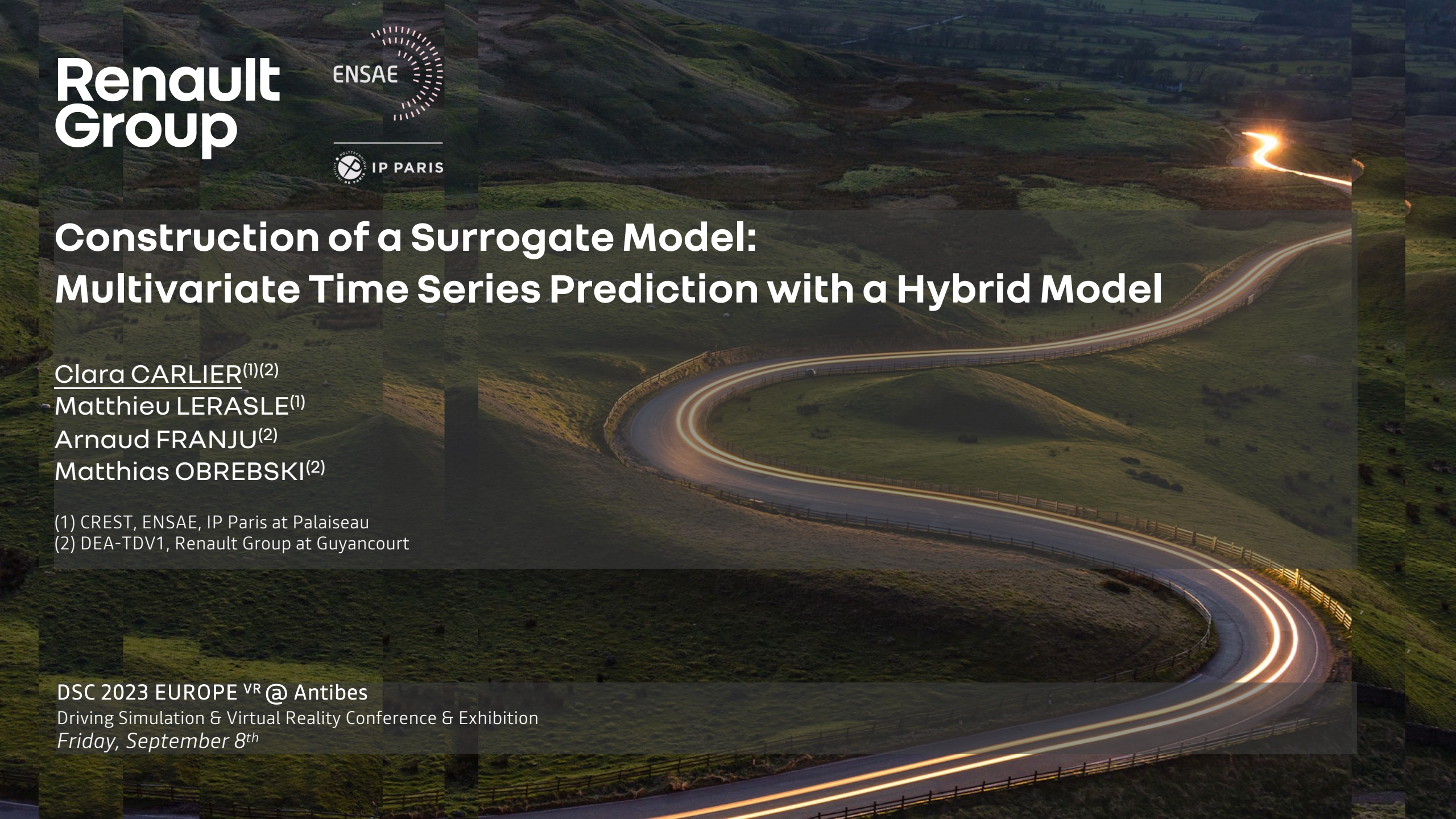

Construction of a Surrogate Model: Multivariate Time Series Prediction with a Hybrid Model

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Driving Simulation & Virtual Reality Conference & Exhibition
Friday, September 8th

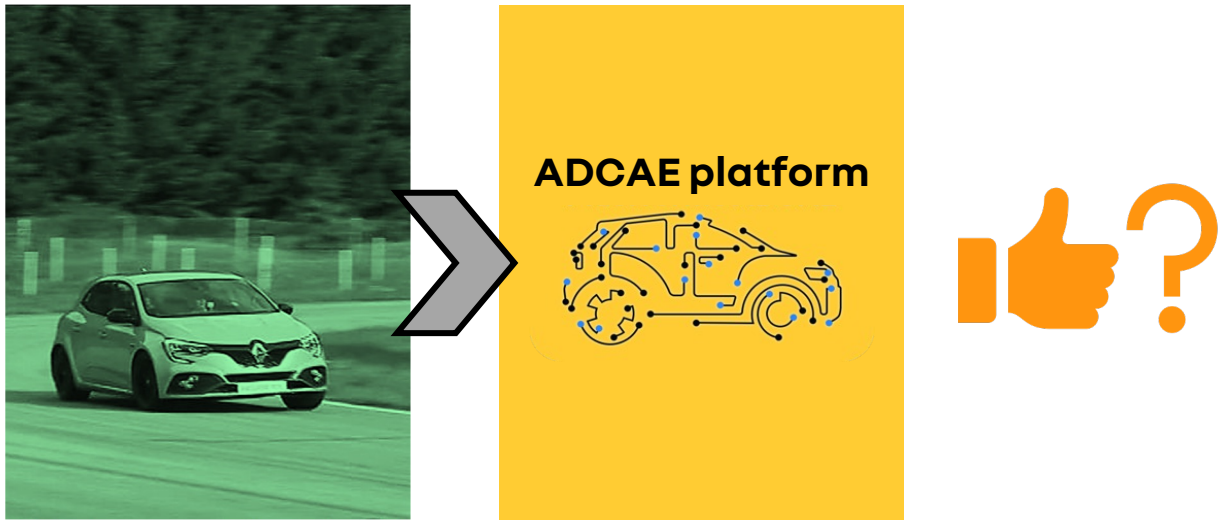
Summary

01

Introduction

BACKGROUND, ISSUES AND OBJECTIVES

01 – Introduction: background, issues and objectives



Real-life on-track experiments
€€€

Simulated experiments

CONTEXT: Validation and certification of autonomous vehicles

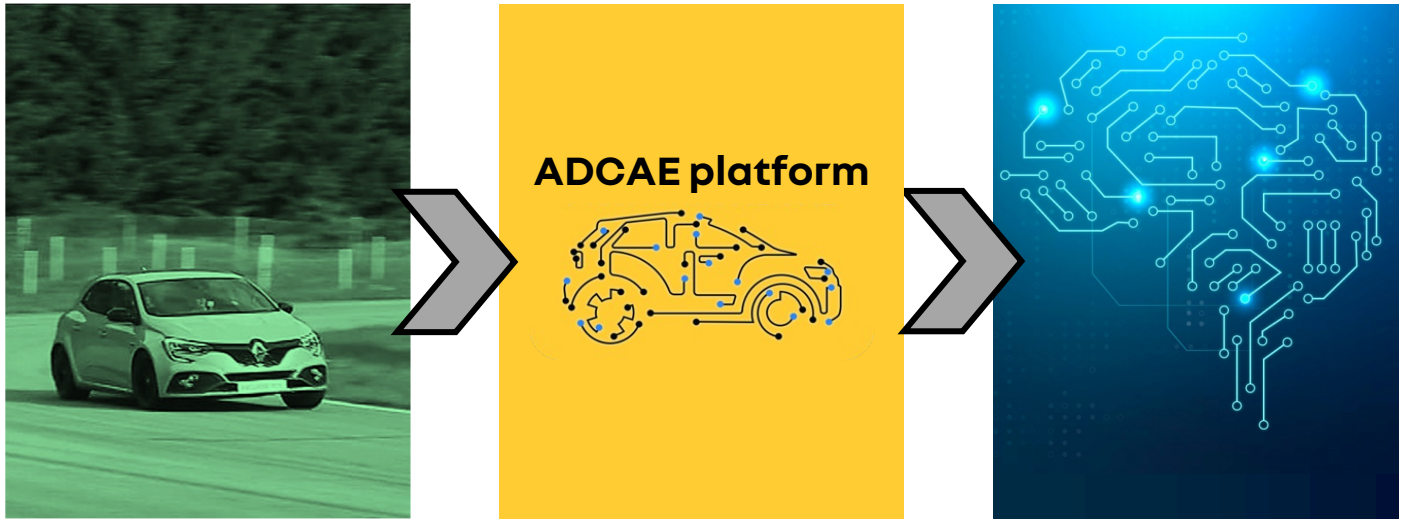
- Real-life on-track experiments are costly and time-consuming
- Use the simulator through simulated experiments to integrate them into the vehicle certification and homologation process

Are digital simulations sufficiently correlated with reality to be used legally?

GLOBAL OBJECTIVE: Simulator calibration

- Develop a methodology for gauging the quality of simulations and adapting their use, in order to prove that it is possible to supplement or even replace track tests with simulator tests

01 – Introduction: background, issues and objectives



Real-life on-track experiments
€€€
🕐🕐🕐

Simulated experiments
€€
🕐🕐

Predicted experiments
€
🕐

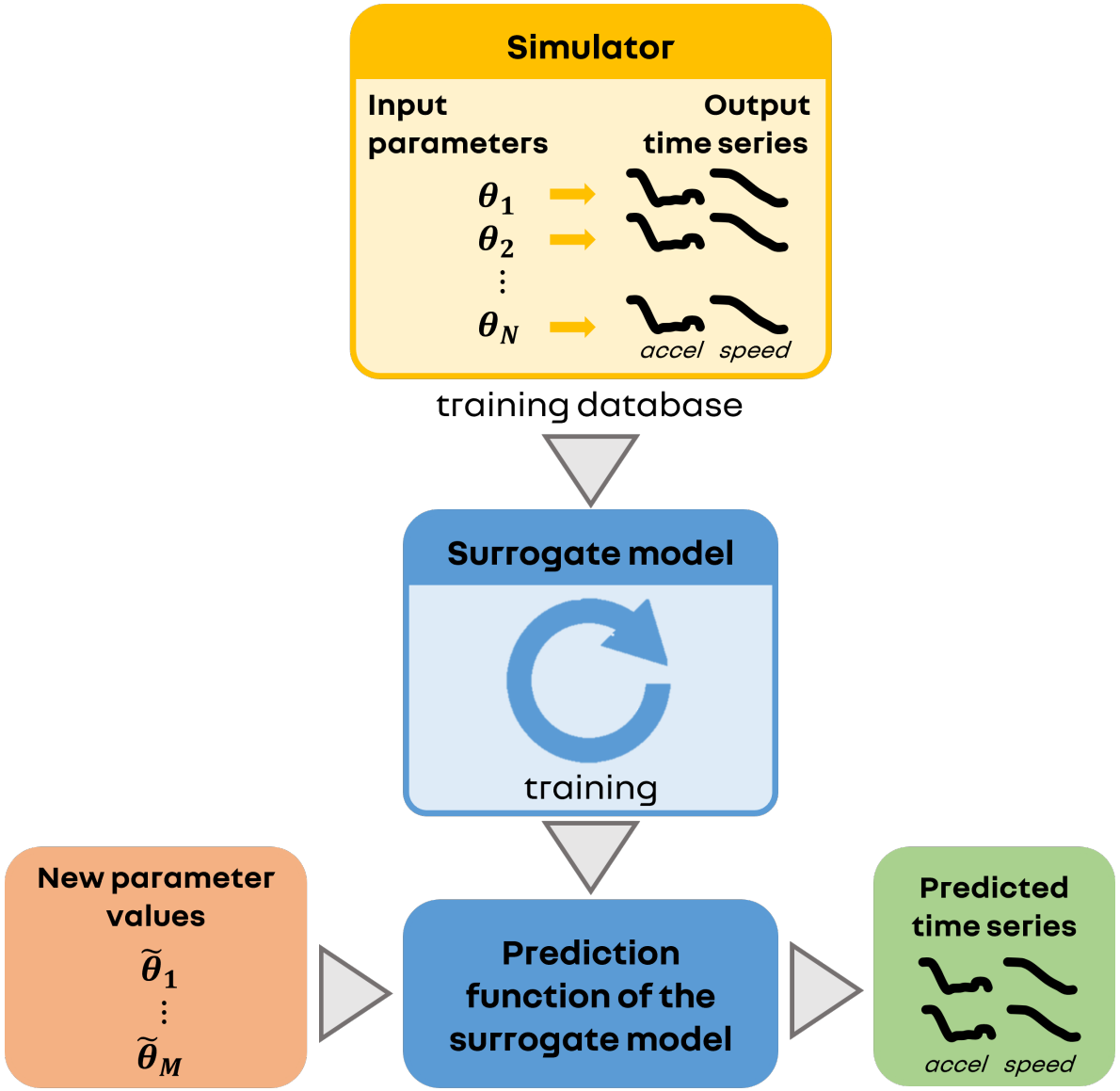
PROBLEM:

The simulator takes a long time to launch (several minutes for each launch), which is restrictive in certain contexts:

- Relaunch the simulator repeatedly in an iterative process
- Massive simulation (~1M)

OBJECTIVE:

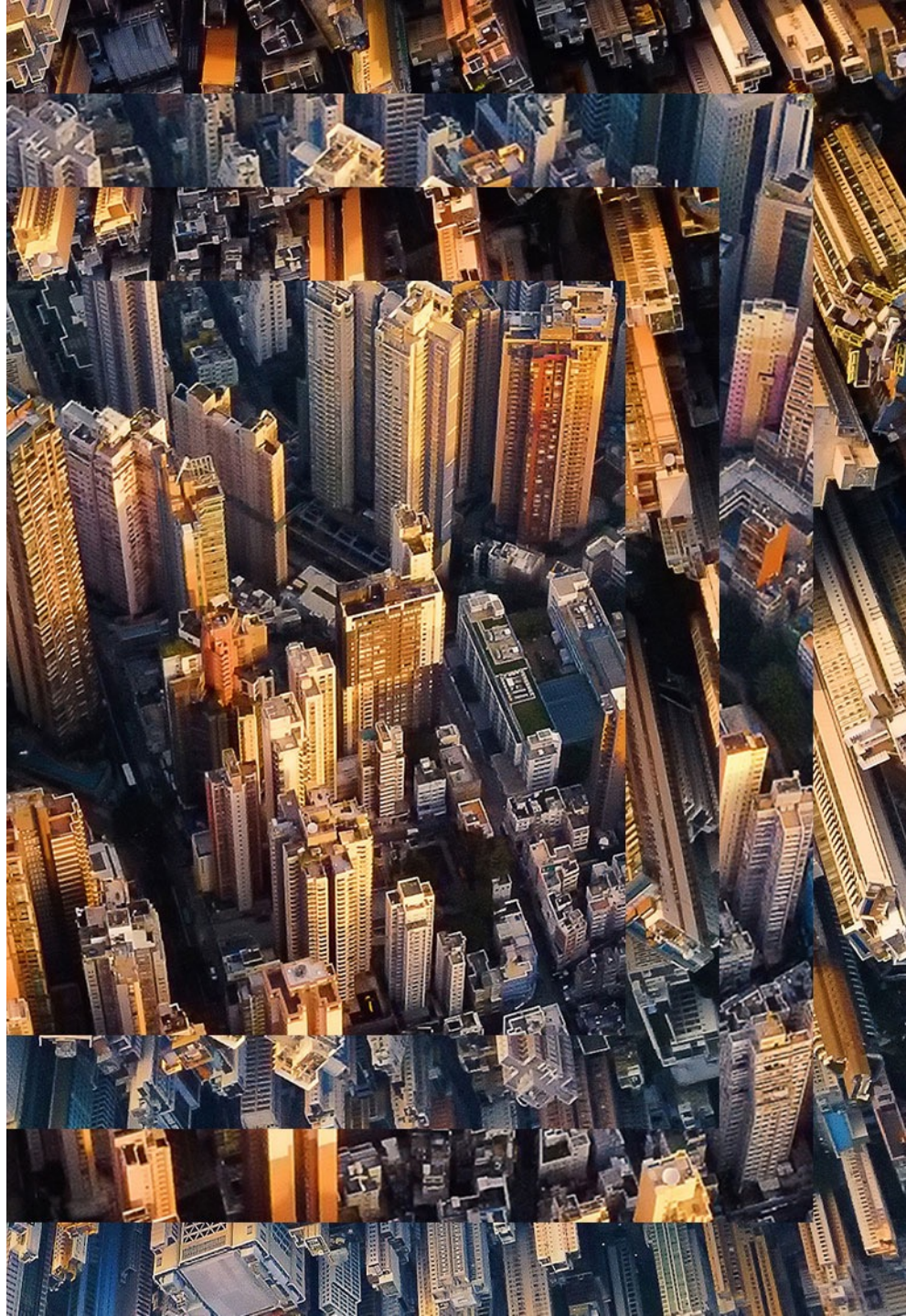
- Build a surrogate model based on Machine Learning methods that will mimic the simulator
- A model that is as accurate as possible while keeping computation times to a minimum


Simulator
Input parameters
Output time series
θ_1
θ_2
θ_N
accel
speed
training database
Surrogate model
training
New parameter values
$\tilde{\theta}_1$
$\tilde{\theta}_M$
Prediction function of the surrogate model
Predicted time series
accel
speed

02

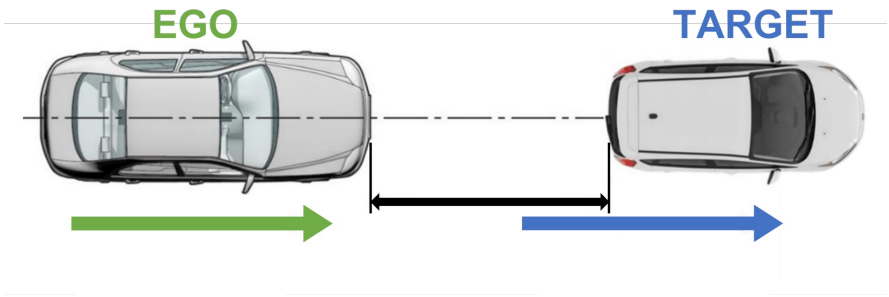
Data description

INPUT PARAMETERS AND OUTPUT TIME SERIES



02 - Data description: input parameters and output time series

CONSIDERED SCENARIO:



Two vehicles in motion: testing the AEB of the second vehicle (EGO) following sudden braking by the first (TARGET).

DATA FORMAT:

- Input: 7-number vector
- Output: 2684-number vector
- 1642 experiments in total

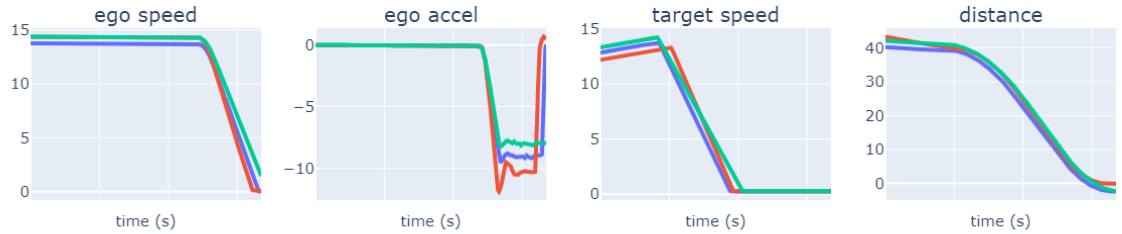
CONSIDERED LOSS:

$$\mathrm{RMSE}(\text{true value}, \text{prediction}) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{TR}_i - P_i)^2}$$

TRAIN	VALIDATION	TEST
1442	*100*	*100*

INPUT PARAMETERS : 7 values

OUTPUT PARAMETERS : 4 time series, 671-time steps



03

Surrogate model construction

CLASSICAL METHODS, AGGREGATION AND *HYBRIDATION*

03 - Surrogate model construction: classical methods, aggregation and hybridation

RMSE $(\times 10^{-2})$ between true and predicted values

- All proposed methods :

		k-NN	KRR	CNN	DF	1-RF	4-RF	PCA-RF
RMSE $(\times 10^{-2})$	train	9.23	0.04	1.22	4.26	1.24	0.71	1.95
	validation	30.15	7.21	2.31	7.05	7.27	3.69	12.35
Training time		0.05 sec	0.22 sec	1 h	13 min	42 sec	53 sec	7.42 sec
Prediction time		0.01 sec	0.02 sec	1.74 sec	0.90 sec	0.09 sec	1.00 sec	1.24 sec

TRAIN

VALIDATION

- More detailed results :

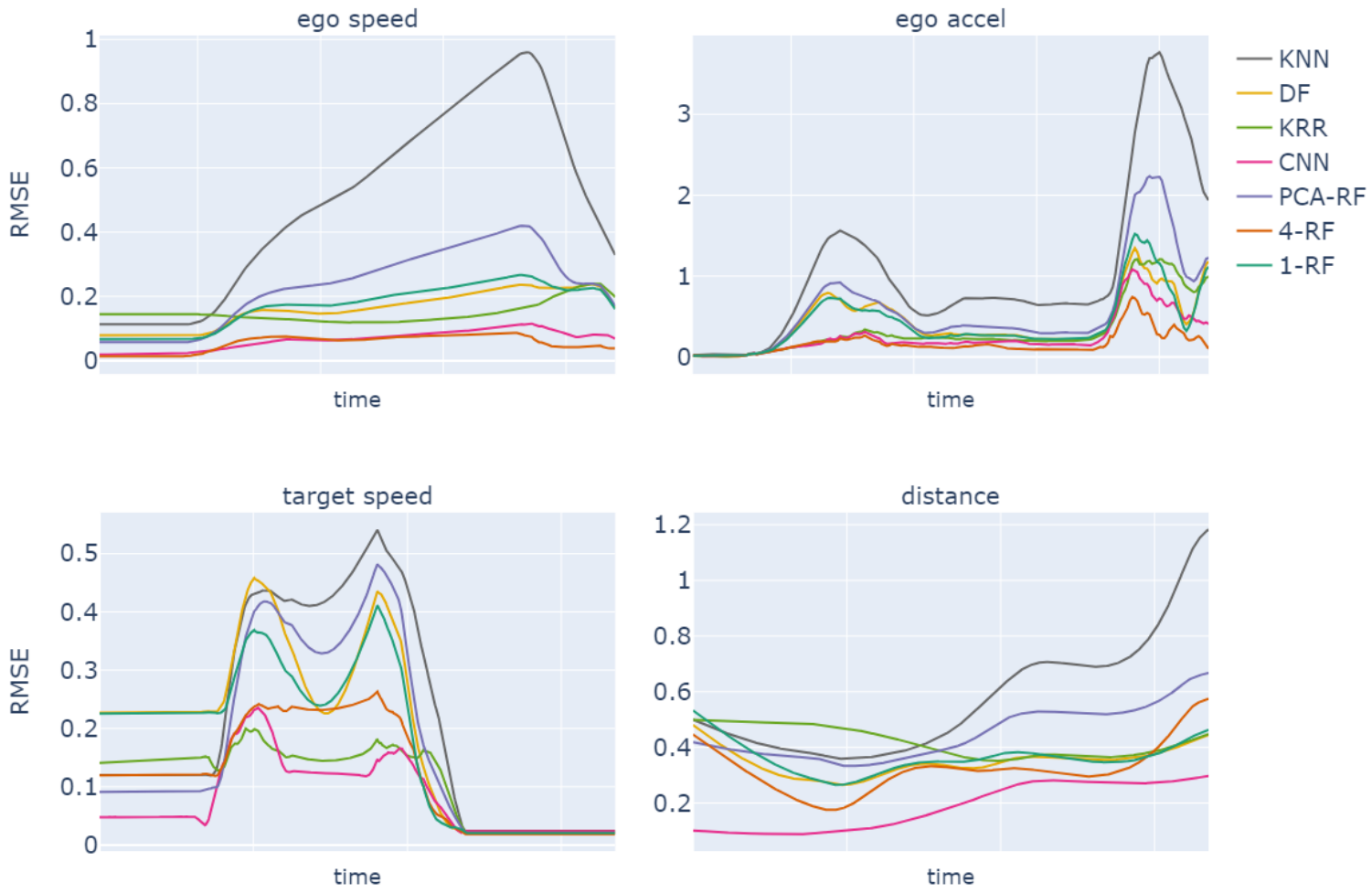
VALIDATION

	Ego speed (m/s)	Ego accel (m/s²)	Target speed (m/s)	Distance (m)
k-NN	11.00	64.77	8.02	36.83
KRR	2.20	7.14	1.63	17.86
CNN	0.18	3.85	**1.06**	**4.16**
DF	1.32	8.88	5.80	12.19
1-RF	1.36	9.54	4.86	13.31
4-RF	**0.12**	**1.47**	2.34	10.84
PCA-RF	2.33	20.53	5.58	20.96

k-NN : k nearest neighbors ; KRR : Kernel Ridge Regression ; CNN : Convolutional Neural Networks ; DF : Deep Forest ; RF : Random Forests ; PCA-RF : Random Forests with PCA

RMSE $(\times 10^{-2})$ between true and predicted values at each time step

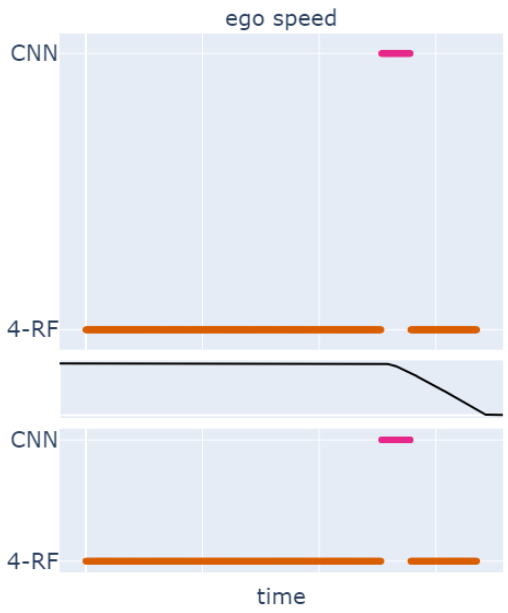
VALIDATION

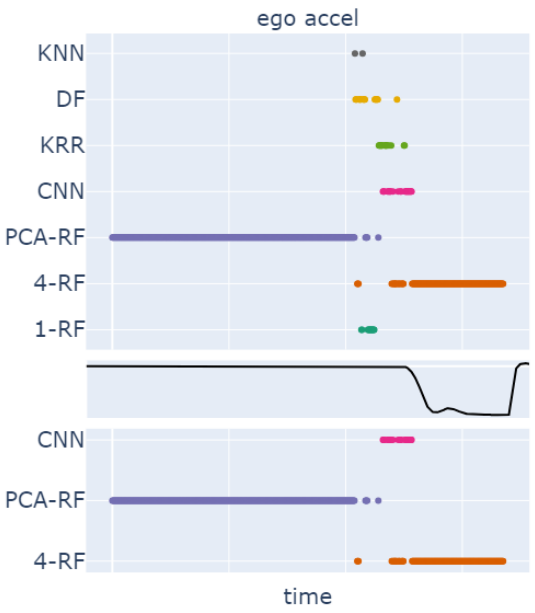


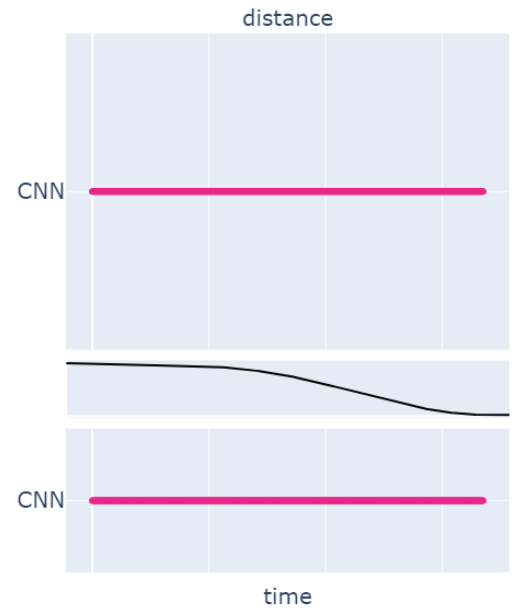
First idea: hybrid models

VALIDATION

One method selected for each time step







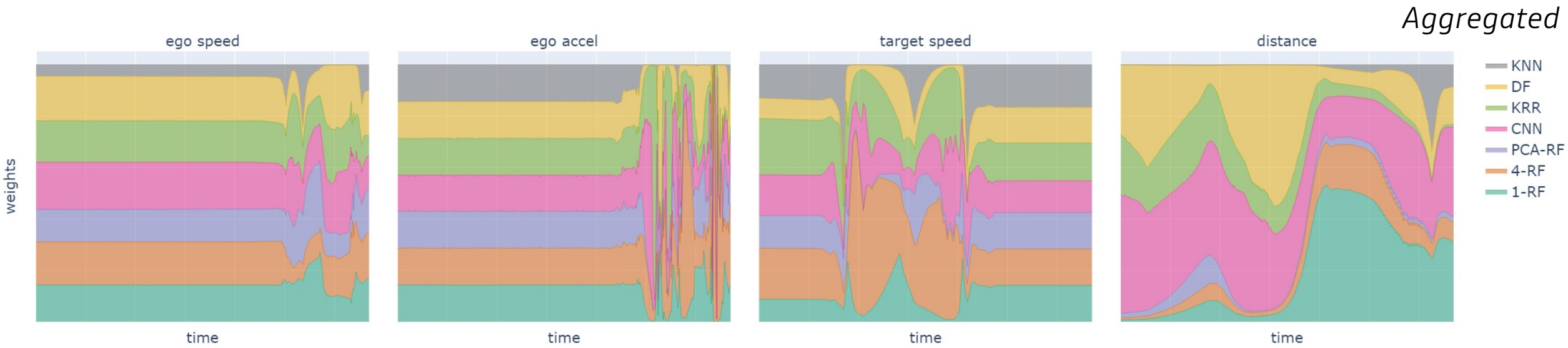
Hybrid 1

Hybrid 2

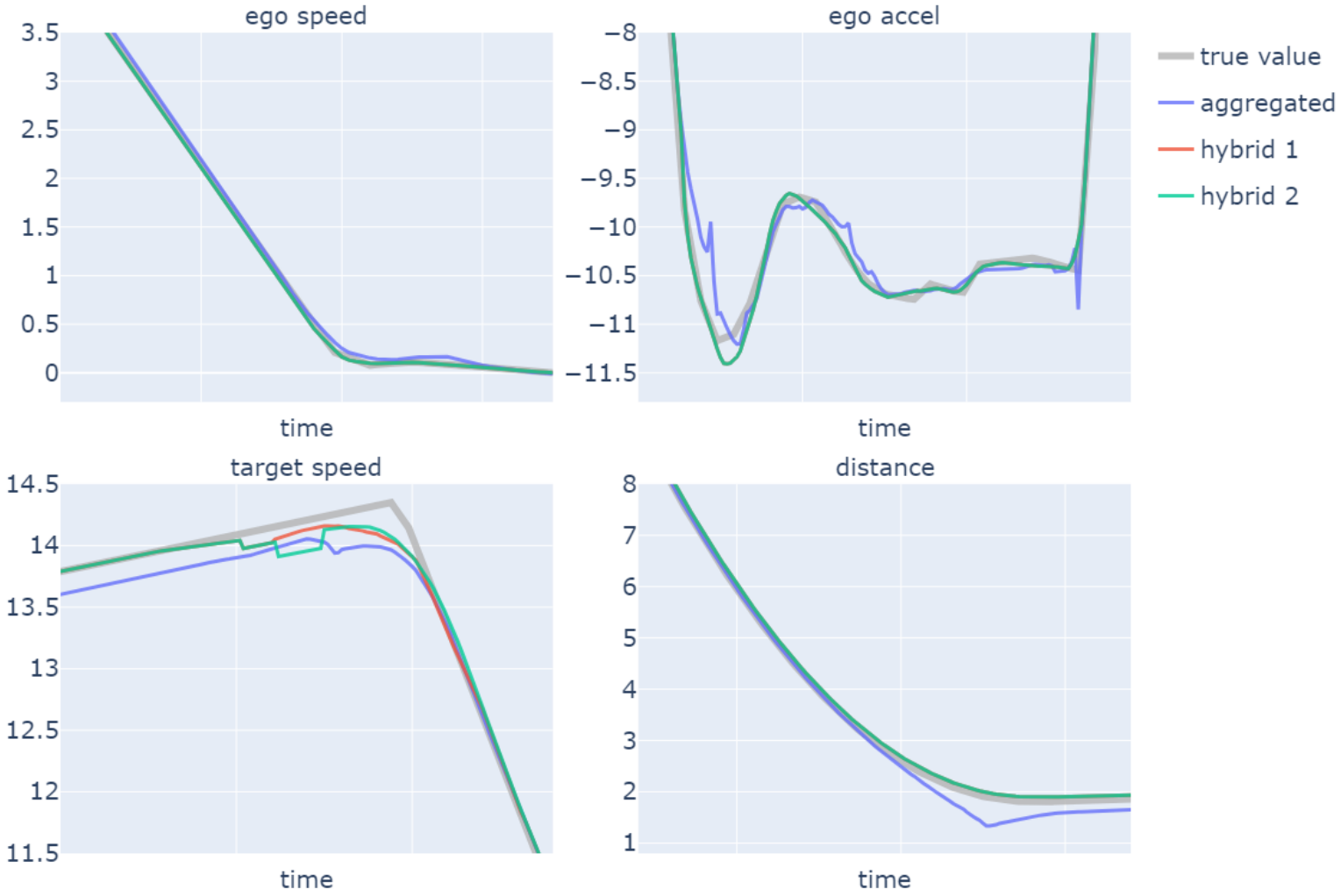
Second idea: expert aggregation

VALIDATION

Retain all methods by assigning them higher or lower weights at each time step



Final results: one concrete example



Final results: RMSE $(\times 10^{-2})$ between true and predicted values

- With validation set (data used to construct the new models):

VALIDATION

	Ego speed	Ego accel	Target speed	Distance	Mean
CNN	0.18	3.85	1.06	4.16	2.31
4-RF	0.12	1.47	2.34	10.84	3.69
Hybrid 1	0.11	1.46	0.93	4.16	1.66
Hybrid 2	0.11	1.46	1.04	4.16	1.69
Aggregated	**0.07**	**0.59**	**0.24**	**1.36**	**0.56**

- With test set (never-used data):

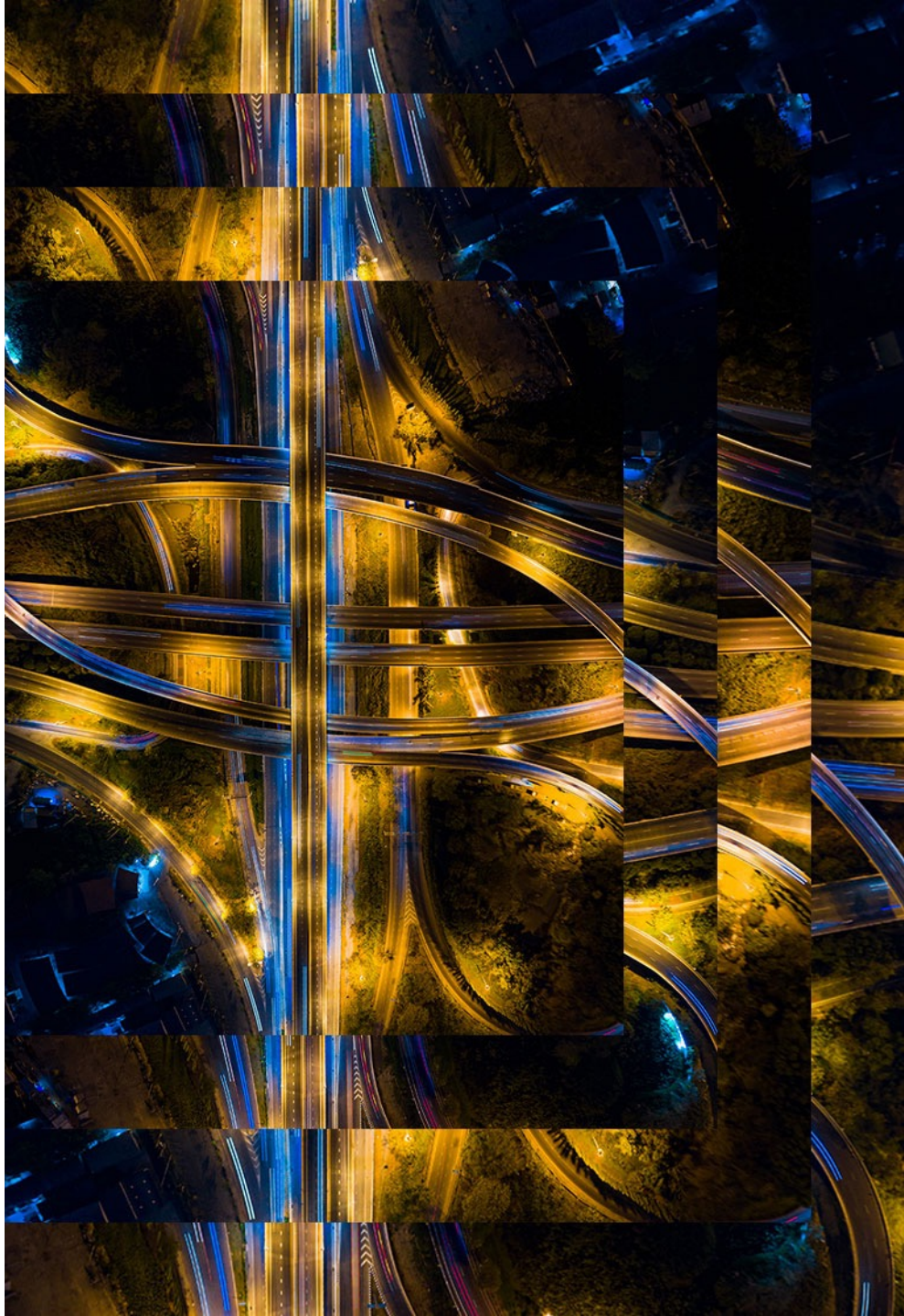
TEST

	Ego speed	Ego accel	Target speed	Distance	Mean
CNN	0.23	3.34	1.00	2.52	1.77
4-RF	0.13	1.36	2.36	9.84	3.42
Hybrid 1	0.12	1.35	1.12	2.52	1.28
Hybrid 2	0.12	1.35	**1.00**	2.52	**1.25**
Aggregated	0.64	3.81	1.35	4.97	2.69

04

Conclusion

NUMERICAL RESULTS AND COMPUTATION TIMES



04 – Conclusion: numerical results and computation times

- **Calculation times:**

	CNN	4-RF	Hybrid 1 (+)	Hybrid 2 (+)	Aggregated (+)
Training	59 min	53 sec	0.29 sec	0.18 sec	2 min 13
Prediction	1.39 sec	0.15 sec	10.25 sec	8.59 sec	2 min 17

(+) add the prediction times for each method

- **To generate 50,000 experiments in several stages:**

4-RF	Hybrid 2	Simulator *
1 minute	1 hour	5 days

**stop and restart the simulator at each step*

- **To conclude :**
  - Mixing models gives better results.
  - The whole process increases calculation times but is still faster than using the simulator.

Choice to do: trade-off between calculation time and accuracy


Thank you