# C-ITS services and advanced vehicle control for complex traffic scenarios

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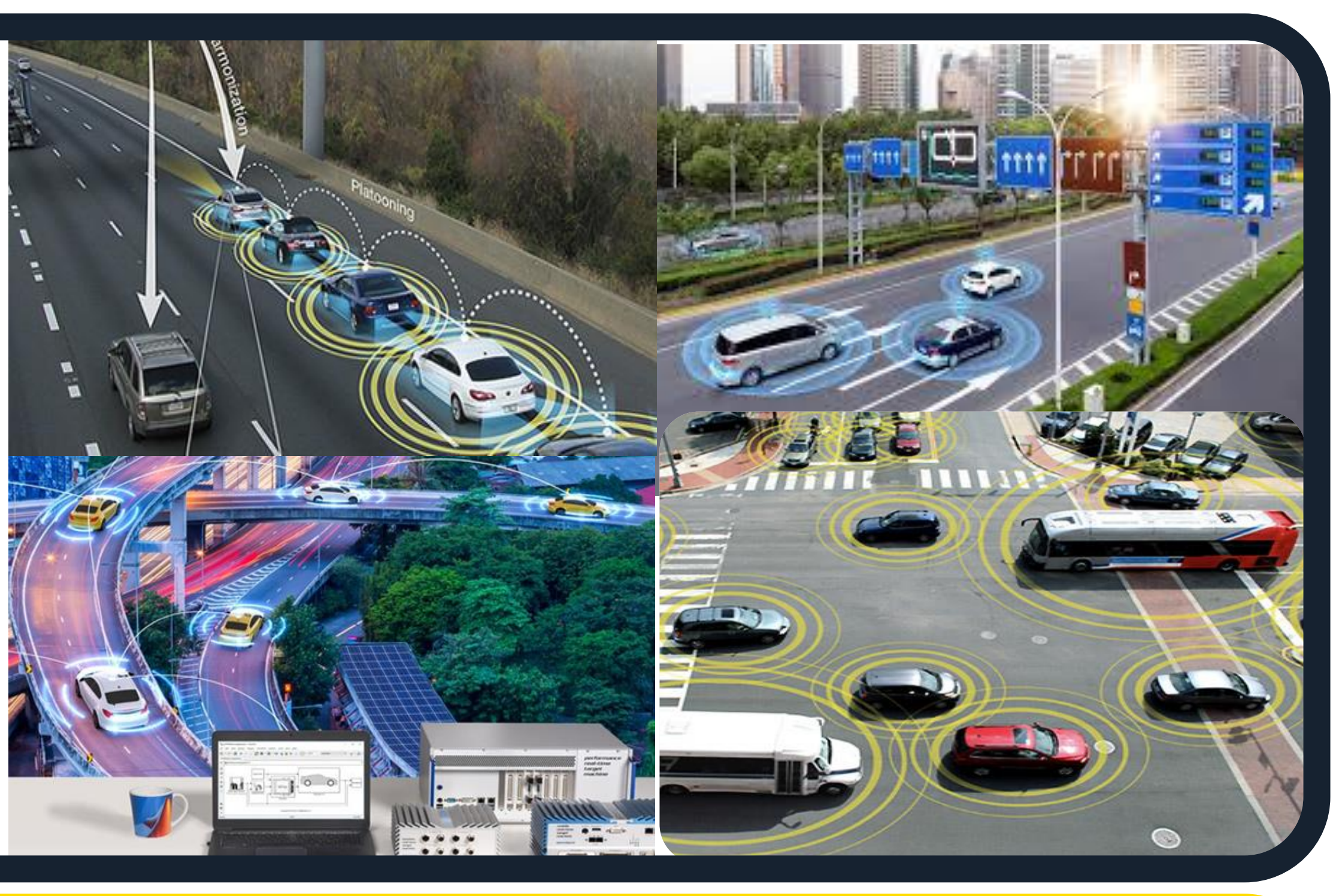
## RESEARCH TOPIC

- Develop innovative C-ITS strategies for cooperation between vehicles and between vehicles and infrastructures based on V2X communication; this aim includes the development of reliable and resilient control architectures to increase the performance of automated and connected driving.
- Develop a virtual simulation environment to test and validate C-ITS strategies in several different complex traffic scenarios.

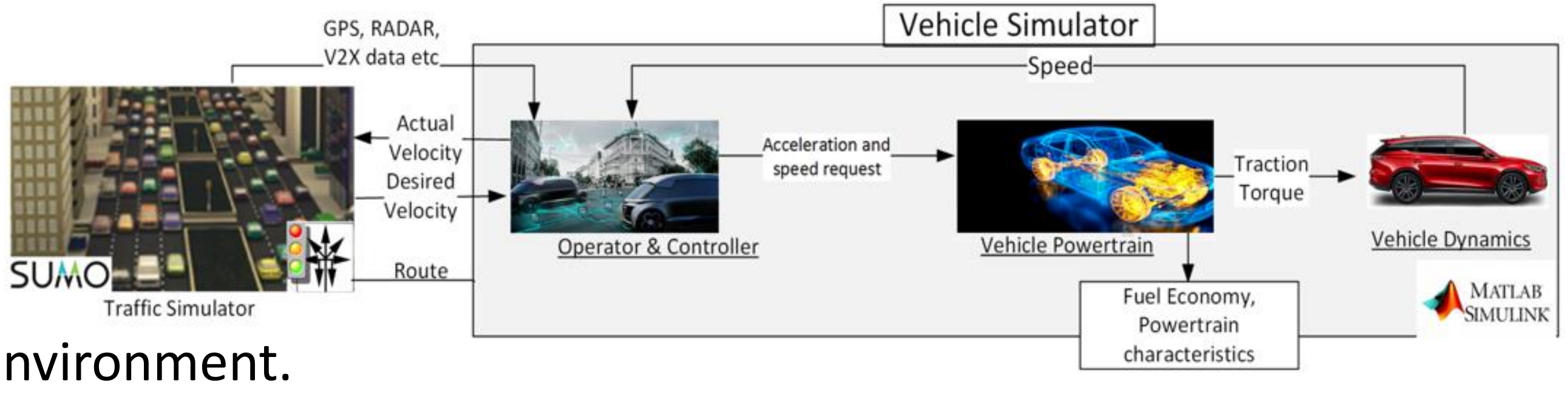
## MOTIVATIONS

- Qualitative and quantitative evaluation of C-ITS strategies are usually performed in simplified conditions, e.g., simplified/neglected road traffic environment, predefined manoeuvrers and linear vehicle dynamics model.
- New autonomous/automated driving systems must be resilient to uncertainties, as well as reliable and robust in any traffic situation
- The idea is to tailor the theoretical results with respect to practical problems, e.g., mixed traffic flow, heterogeneous vehicles and nonlinear uncertain vehicles models.



## MiTraS SIMULATION PLATFORM

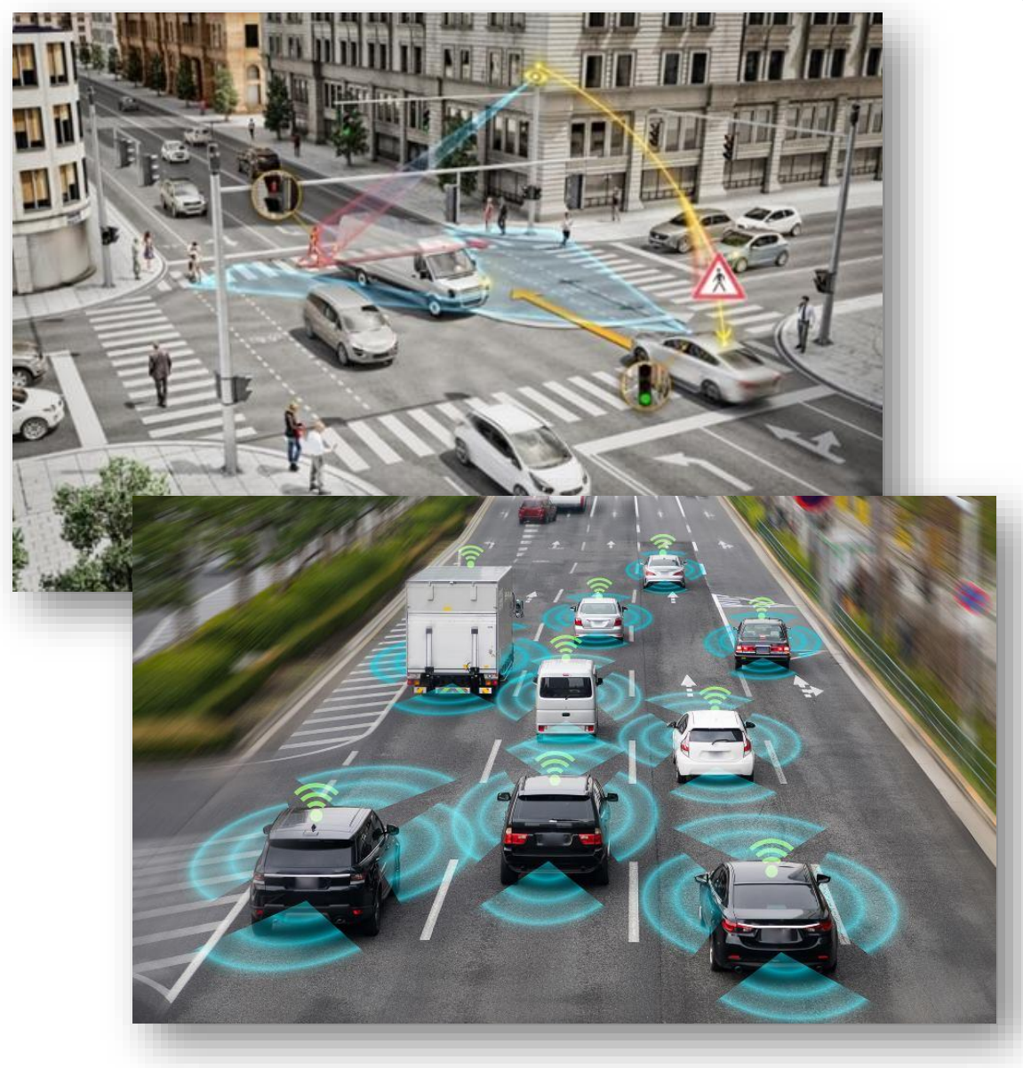
Mixed Traffic Simulator (MiTraS) co-simulation platform has been designed and implemented for validating different control strategies in realistic road traffic scenarios (e.g., in presence of human-driven vehicles, road intersections, traffic lights and so on).



- Matlab/Simulink
  - Vehicle Dynamics;
  - Sensors;
  - 3D road environment;
- SUMO for road traffic environment.

## TRAFFIC SCENARIOS

- Urban traffic scenarios
  - Unsignalized/Signalized intersection;
  - Turn maneuver.
- Extra-urban traffic scenarios
  - Platooning;
  - Lane change/overtaking maneuver;
  - Road section restriction;
  - Emergency Breaking.



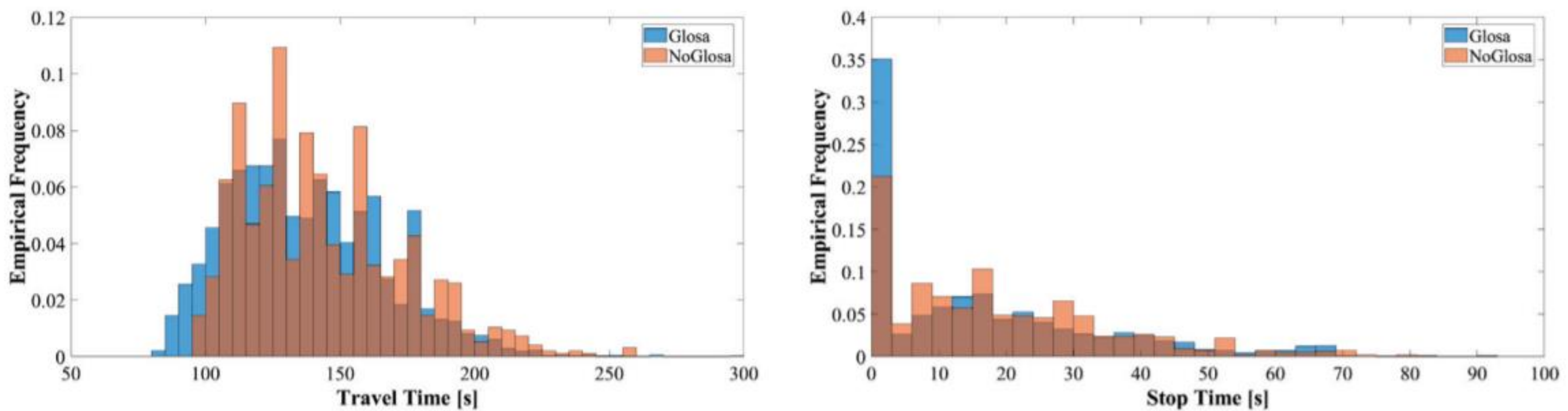
## URBAN SIGNALIZED INTERSECTION CROSSING

Green Light Optimal Speed Advisory (GLOSA) service provides an optimal speed profile to cross an intersection exploiting Traffic Light Signals information

$$\begin{aligned} &\textit{minimise} && f(v) \\ &\textit{subject to} && V_{min} \le V_r \le V_{max} \\ &&& a_{min} \le a_r \le a_{max} \\ &&& \text{phase}_\text{i}\,(\text{t} + \Delta t_{tls}(V_r)) = Green \end{aligned}$$

**Algorithm 1** GLOSA Algorithm executed when the Ego-Vehicle enters the communication range of upstream TLS $i$

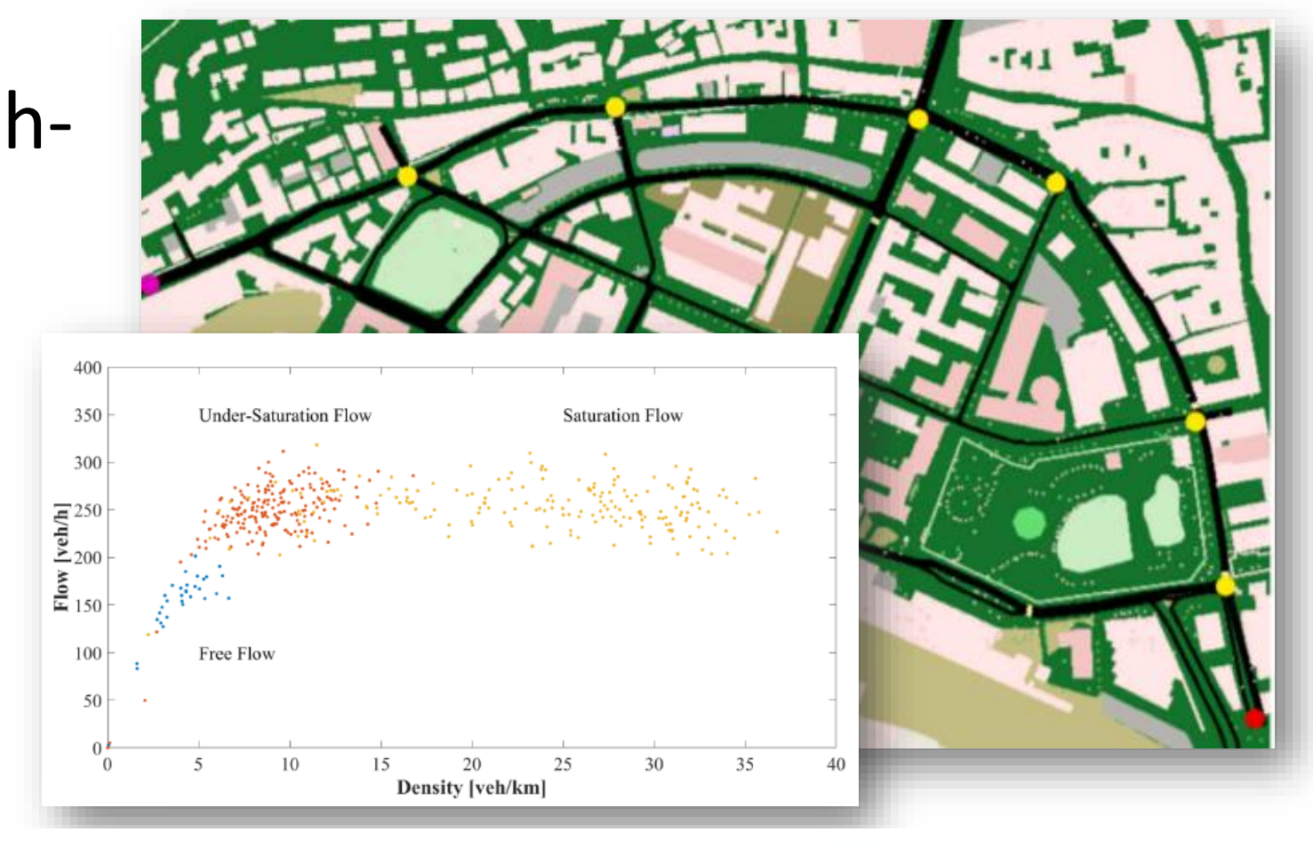
```
Find the next-one upstream TLS
Calculate time to reach the TLS $\Delta t_{tls,0}$ with actual speed and acceleration
Check phase at time $t + \Delta t_{tls,0}$
if Green then
    Calculate remaining time to green phase $\Delta t_{tls,g}$
    Calculate reference speed for $t + \Delta t_{tls}(V_r)$ : $V_r \in [V_{min}, V_{max}]$ & $\Delta t_{tls}(V_r) \ge \Delta t_{tls,g}$
else
    Calculate time to next green phase $\Delta t_{tls,ng}$
    Calculate reference speed for $t + \Delta t_{tls}(V_r)$ : $V_r \in [V_{min}, V_{max}]$ & $\Delta t_{tls}(V_r) \ge \Delta t_{tls,ng}$
end
```

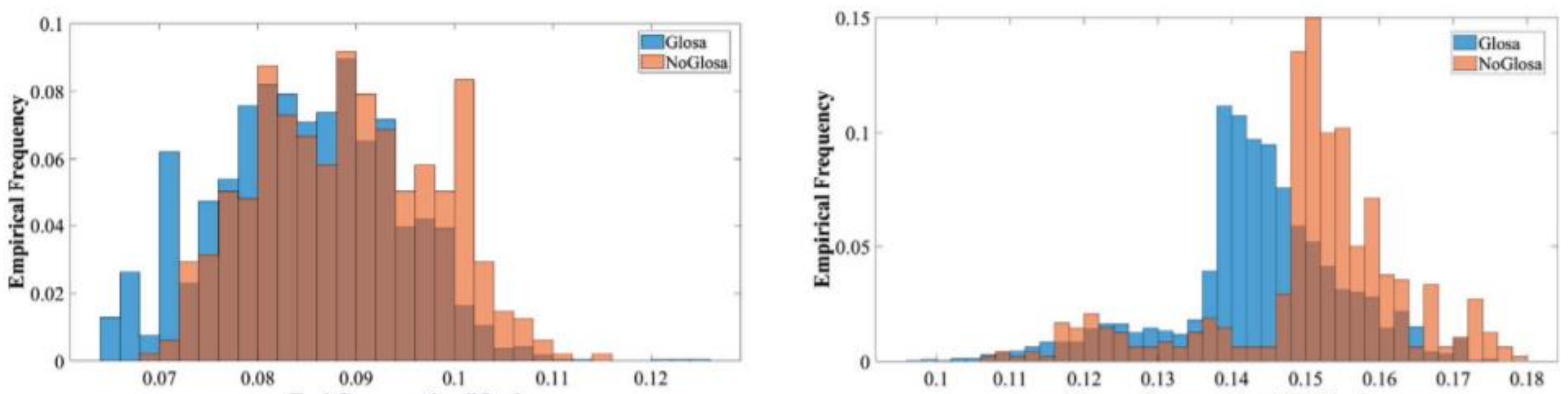


The GLOSA algorithm reduces travel time and stop time of about 5% and 13%, respectively.

One-factor-at-a-time (OFAT) approach-based experiment

- Engine type
- Traffic conditions
- TLS cycle duration
- Communication distance
- Minimum speed
- Traffic signal phase condition





The GLOSA algorithm reduces consumption if about 5% for the endothermic case and 4.72% for the electric.

## COOPERATIVE CONTROL STRATEGY FOR HETEROGENEOUS NONLINEAR UNCERTAIN AUTONOMOUS VEHICLES PLATOON

- Nonlinearities must be considered for a more accurate and realistic problem formulation and control design
- Robustness w.r.t. uncertain nonlinear dynamics is crucial in cooperative driving applications to deal with mismatches between the actual plant and its control-oriented model
- Platooning maneuvers must be performed considering the surrounding traffic conditions

$$\dot{p}_i(t) = v_i(t)$$

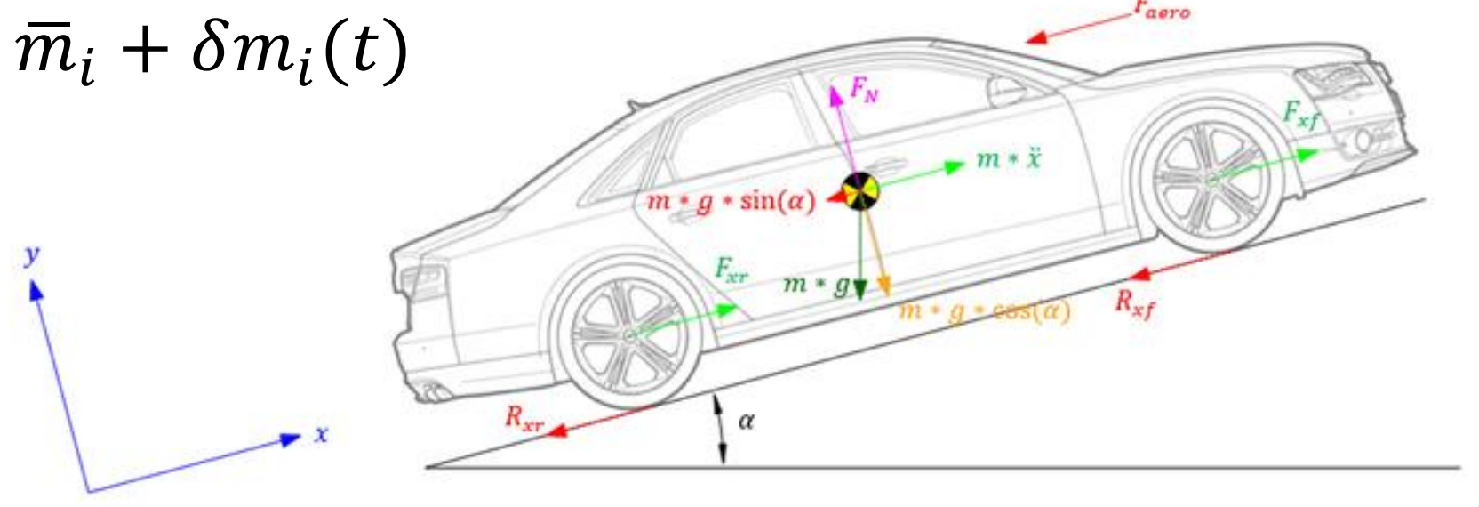
$$v_i(t) = \frac{\eta_i}{R_i m_i} u_i(t) - g\sin(\theta_i(t)) - g\mu_i(t)\cos(\theta\,(t)) - \frac{\rho}{2m_i(t)}\, C_{D_i}(t)\left(1 - \phi_i\left(p_i\,(t), p_{i-1}\,(t)\right)\right) C_{h,i}(t)\, A_{f_i}(t)\, v_i^2(t)$$

$$C_{D,i}(t) = \bar{C}_{D,i} + \delta C_{D,i}(t) \qquad \xi_i(t) = \bar{\xi}_i + \delta\xi_i(t)$$

$$C_{h,i}(t) = \bar{C}_{h,i} + \delta C_{h,i}(t) \qquad R_i(t) = \bar{R}_i + \delta R_i(t)$$

$$A_{f,i}(t) = \bar{A}_{f,i} + \delta A_{f,i}(t) \qquad \mu_i(t) = \bar{\mu}_i + \delta\mu_i(t)$$

$$m_i(t) = \bar{m}_i + \delta m_i(t)$$



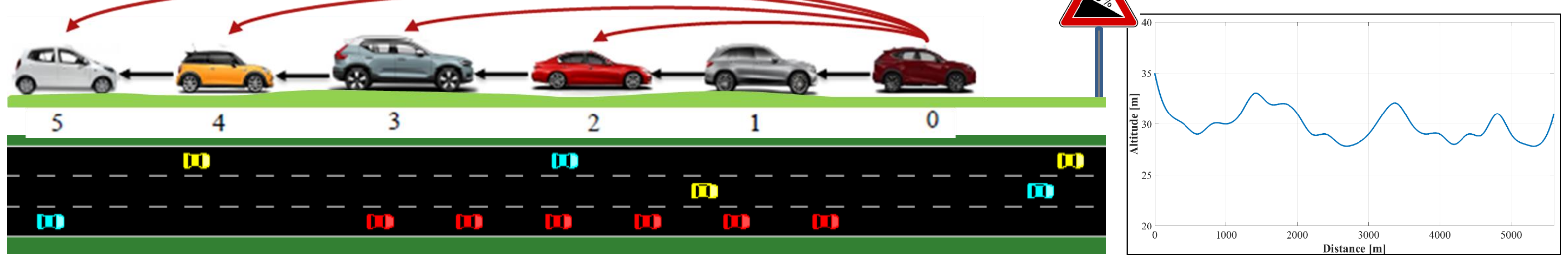
## PROPOSED SOLUTION

**Algorithm 1** Motion Control Strategy

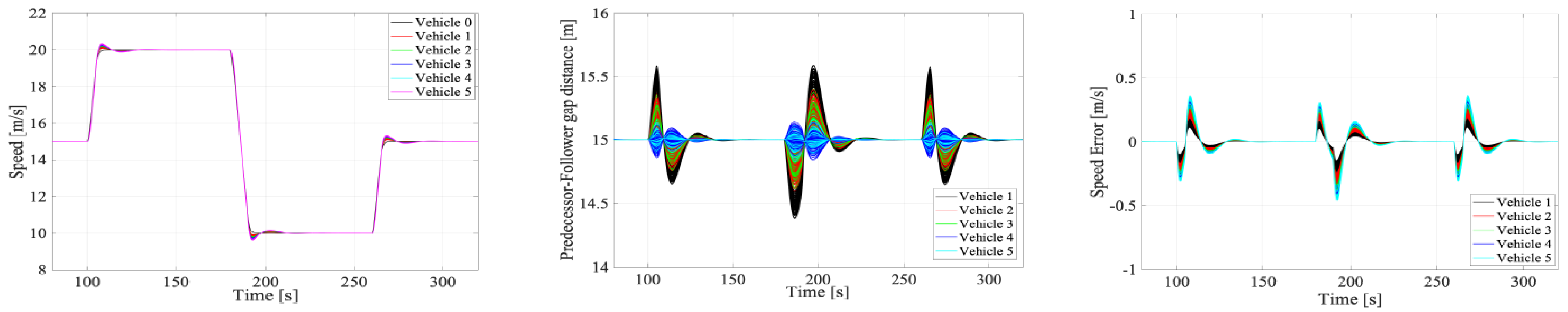
```
Data: Neighbors Information $x_j(t)$.
Result: Control Input $u_{i,\sigma}(t)$.
Declarations
        $out_i = [0,1]$;
        $N$ = number of vehicles within the platoon;
        $t_s$ = manoeuvre start time;
        $c_f$ = collision flag.
Initialization
        $N = 5$.
    Scenario 1: $out_i = 0,\ i = (1,\dots,N)$;
    Scenario 2: $out_3 = 1$;
                $out_i = 0,\ i = (1,\dots,N)\ \&\ i \neq 3$;
                $T_m = 50$.
Distributed Robust PI Control Action
    $u_{i,\sigma}(t) = -\alpha_\sigma \bar{b}_i^{-1} K_{p,\sigma} \sum_{j=0}^{N} a_{ij,\sigma}\left(p_i(t) - p_j(t) - d_{ij}\right)$
        $- \alpha_\sigma \bar{b}_i^{-1} K_{i,\sigma} \sum_{j=0}^{N} a_{ij,\sigma} \int_0^t \left(p_i(\tau) - p_j(\tau) - d_{ij}\right) d\tau$
        $- \alpha_\sigma \bar{b}_i^{-1} K_{d,\sigma} \sum_{j=0}^{N} a_{ij,\sigma}\left(v_i(t) - v_j(t)\right)$.
 Motion Control
 for i=1 to N do
    if $out_i == 1\ \&\ t \ge T_m$ then
        Generate reference lane-change trajectory;
        Detect any foes HDVs for the generated trajectory;
        if $c_f$ is OFF then
            Start the lane change manoeuvre;
        else
            Wait to start the lane-change manoeuvre;
            Compute the distributed robust PI control action;
        end
    else
        Compute the distributed robust PI control action;
    end
end
```

## HETEROGENEOUS NONLINEAR UNCERTAINPLATOONING APPLICATION

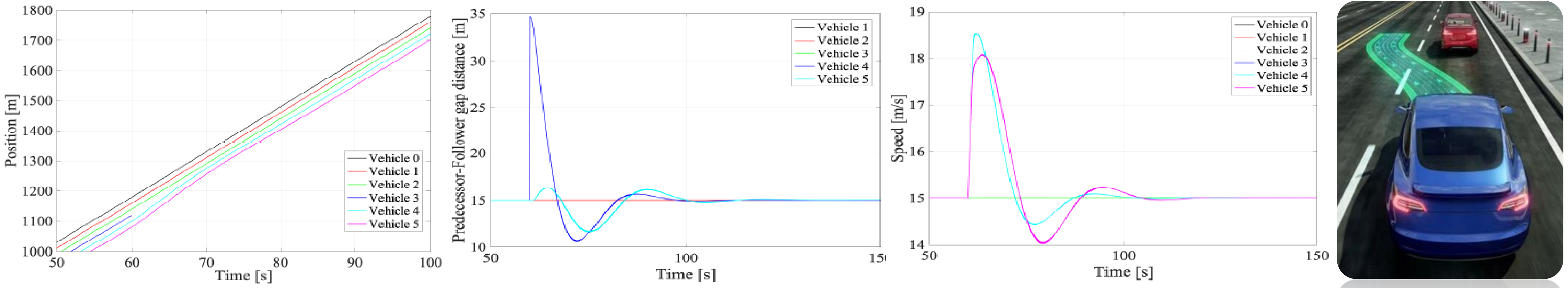
- The aim is to guarantee that each vehicle within the platoon tracks the leader speed while preserving a desired inter-vehicle gap distance of *15 [m]*;
- In the case a vehicle perform a cut-off manoeuvre, avoiding collision with HDVs, the platoon has to be recreated.



| Vehicle Parameters | $m_i$ $[kg]$ | $\eta_i$ $[-]$ | $R_i$ $[m]$ | $f_{ri}$ $[-]$ | $C_{D,i}$ $[-]$ | $A_{f,i}$ $[m^2]$ | $a_{max}$ $[m/s^2]$ | $a_{min}$ $[m/s^2]$ |
|---|---|---|---|---|---|---|---|---|
| **0** | 1545 | 0.89 | 0.3060 | 0.020 | 0.28 | 2.3315 | 2.5 | -6.0 |
| **1** | 1015 | 0.89 | 0.2830 | 0.022 | 0.30 | 2.1900 | 2.5 | -6.0 |
| **2** | 1375 | 0.89 | 0.2880 | 0.019 | 0.24 | 2.4000 | 2.5 | -6.0 |
| **3** | 1430 | 0.89 | 0.3284 | 0.021 | 0.28 | 2.4600 | 2.5 | -6.0 |
| **4** | 1067 | 0.89 | 0.2653 | 0.023 | 0.29 | 2.1400 | 2.5 | -6.0 |
| **5** | 1155 | 0.89 | 0.2880 | 0.024 | 0.33 | 2.0400 | 2.5 | -6.0 |
| **Uncertainty** | ±20% | ±5% | ±2% | ±10% | ±10% | ±10% | - | - |



*Leader Tracking* performance for trapezoidal speed profile. Robustness analysis via the Monte Carlo Method. Time history of: (a) vehicles speed; (b) inter-vehicle distance; (c) speed error.



*Leave from-the-middle* maneuver performances. Robustness analysis via the Monte Carlo Method. Time history of: (a) vehicles position; (b) inter-vehicle distance; (c) vehicles speed.