A two-level urban traffic control for autonomous vehicles to improve network-wide performance

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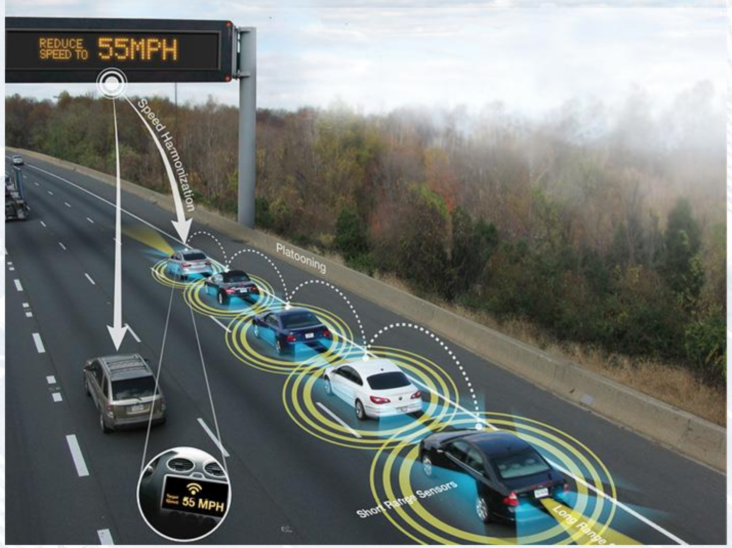
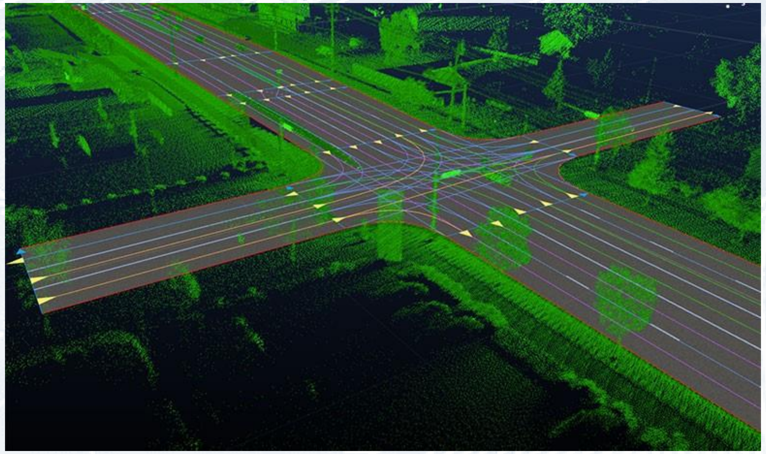
Motivation:
- Manual versus autonomous vehicles
- Also on traffic network level



Autonomous vehicles at junctions
→ autonomous intersection without physical traffic lights

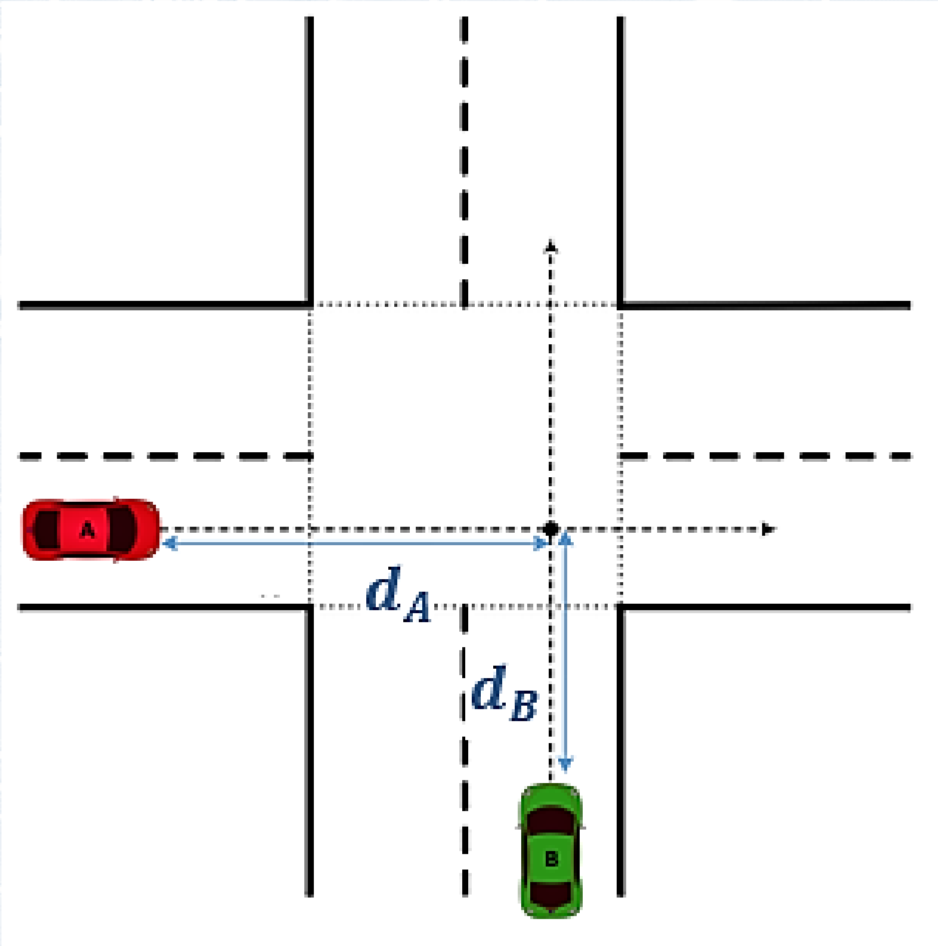


Junction traffic model

$$\vec{S}(k+1) = \vec{S}(k) + \vec{d}\left(\vec{S}(k)\right) \cdot v(k) \cdot T$$

To avoid collision, condition $|d_A - d_B| > d_{min}$ must be valid at all times.

This constraint is considered later in the control design.



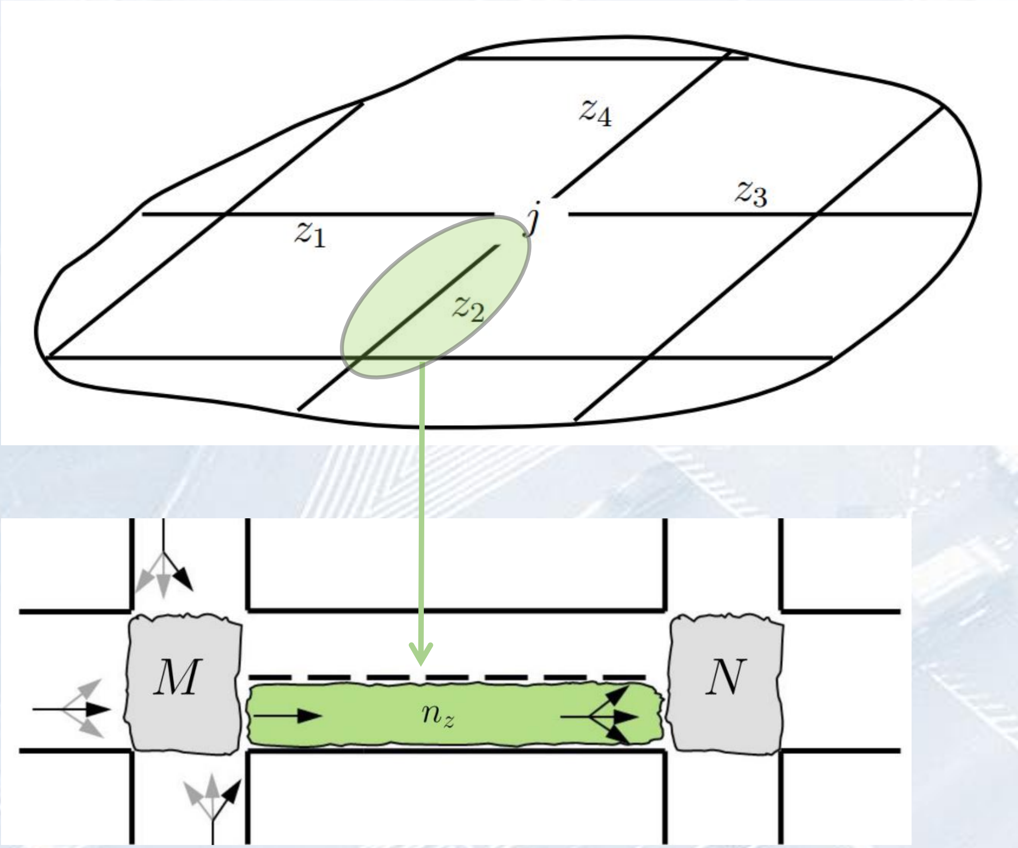
Emission model was also considered in the control design

- Traffic emission mainly consists of *CO*, NO_x, *HC*, and CO_2.
- For microscopic (vehicle based) emission the COPERT IV model was adopted:

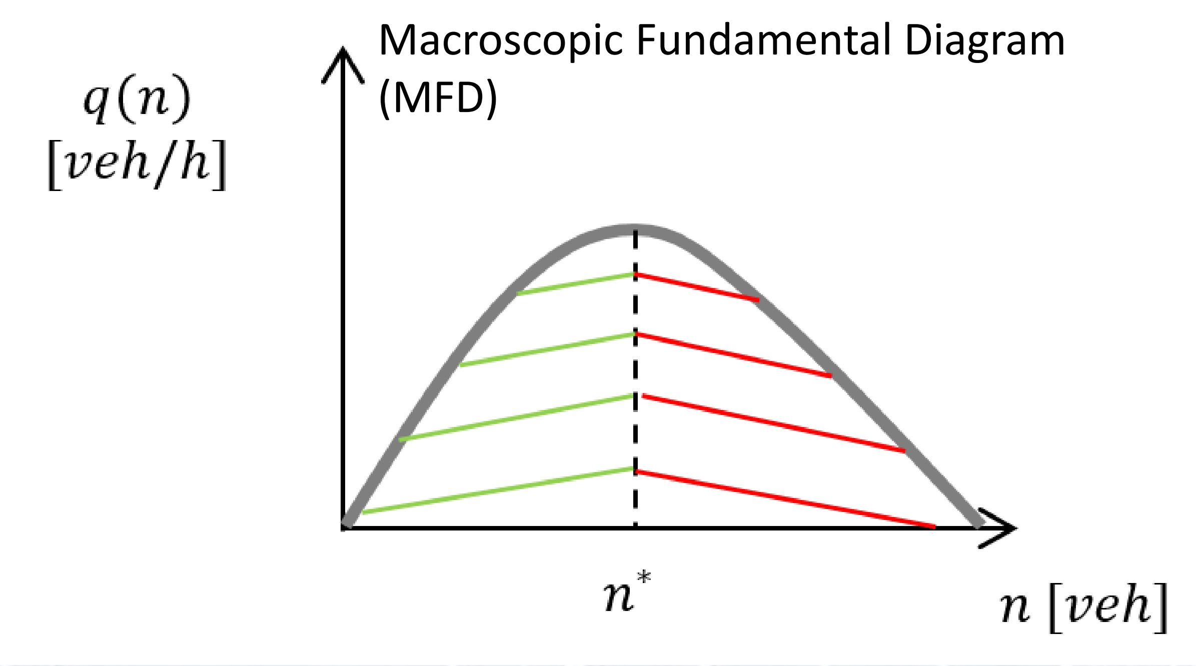
$$ef(v) = \alpha_2^p v^2 + \alpha_1^p v + \alpha_0^p,$$

where α_i^p denotes the emission parameters for pollutant p

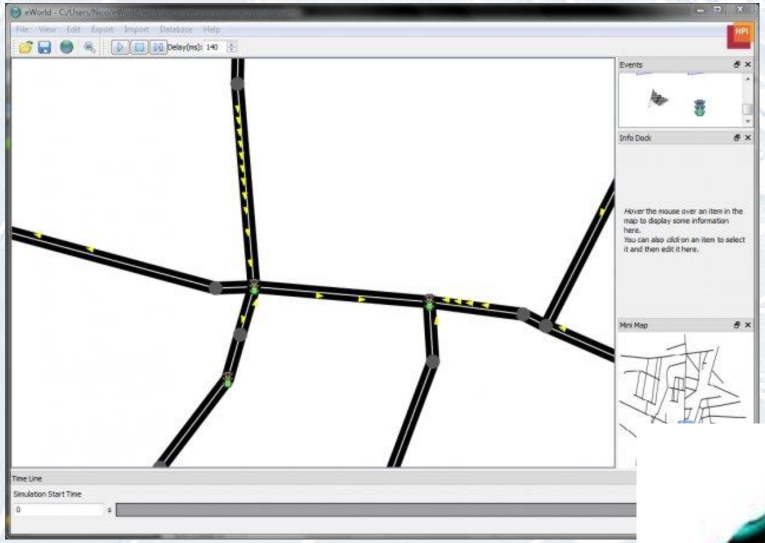
Network traffic model

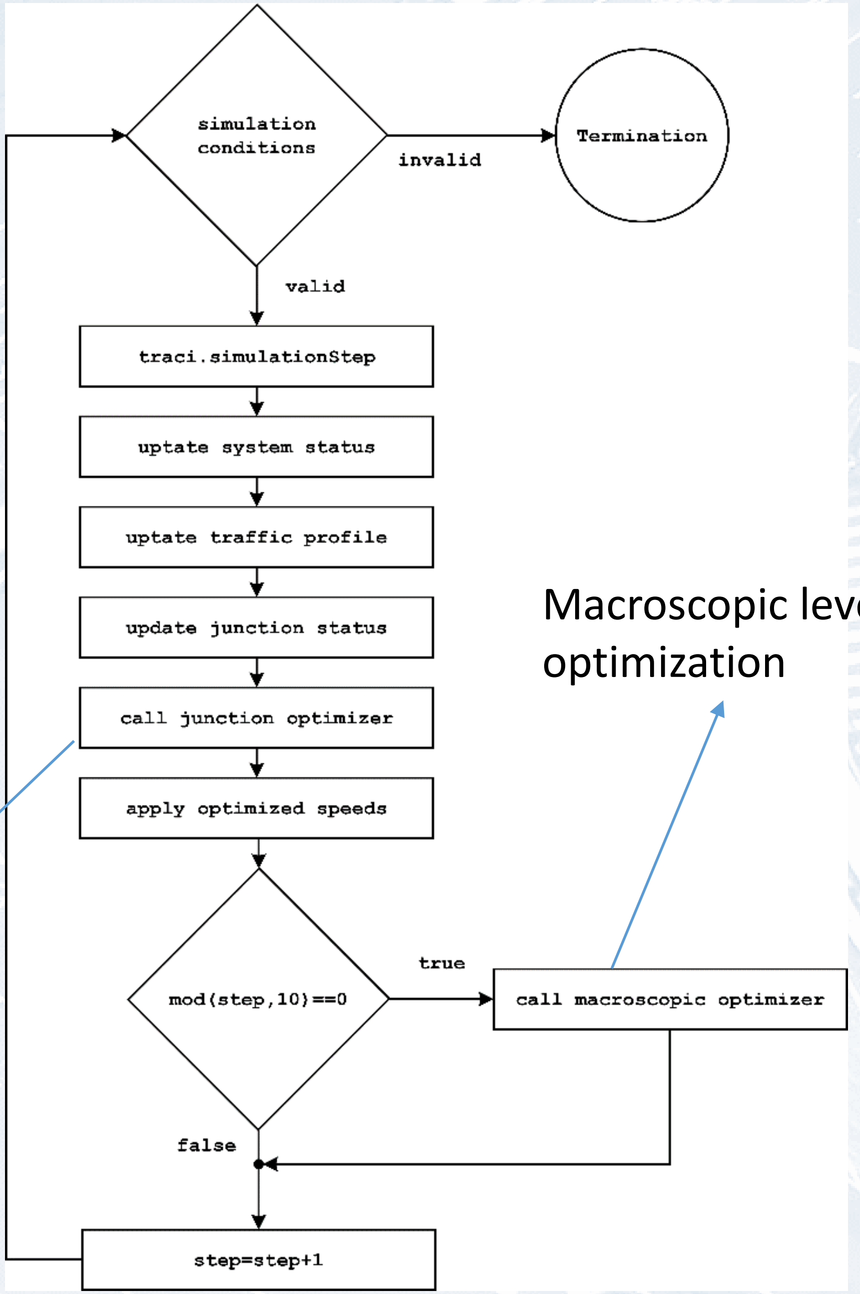


$$n_z(k+1) = n_z(k) + T\left[\sum_{w,z} \alpha_{w,z} q_{w,z}(k) - q_z(k)\right]$$



Two level optimization using SUMO traffic simulator and MATLAB





Macroscopic level optimization

Microscopic level optimization

Low level control in order to avoid collision

→ **Nonlinear Model Predictive Control (MPC)**

$$\min_{u(k+l-1)} \quad J(k),$$

$$s.t. \quad u(k+l-1) \in \mathbb{U},$$
$$x(k+l) \in \mathbb{X},$$
$$l = 1,2,\ldots,K$$

→ Constrained optimization

Highest mobility
Lowest emission

$$J(k) = \sum_{l=1}^{K} \sum_{i=1}^{N_{vehicles}} \left[\alpha[1+p_i]v_i^2(k+l) + \beta[v_i(k+l) - v_i(k+l+1)]^2 + \gamma\, ef_i^{\,2}\big(v_i(k+l)\big)\right],$$

Priority parameter

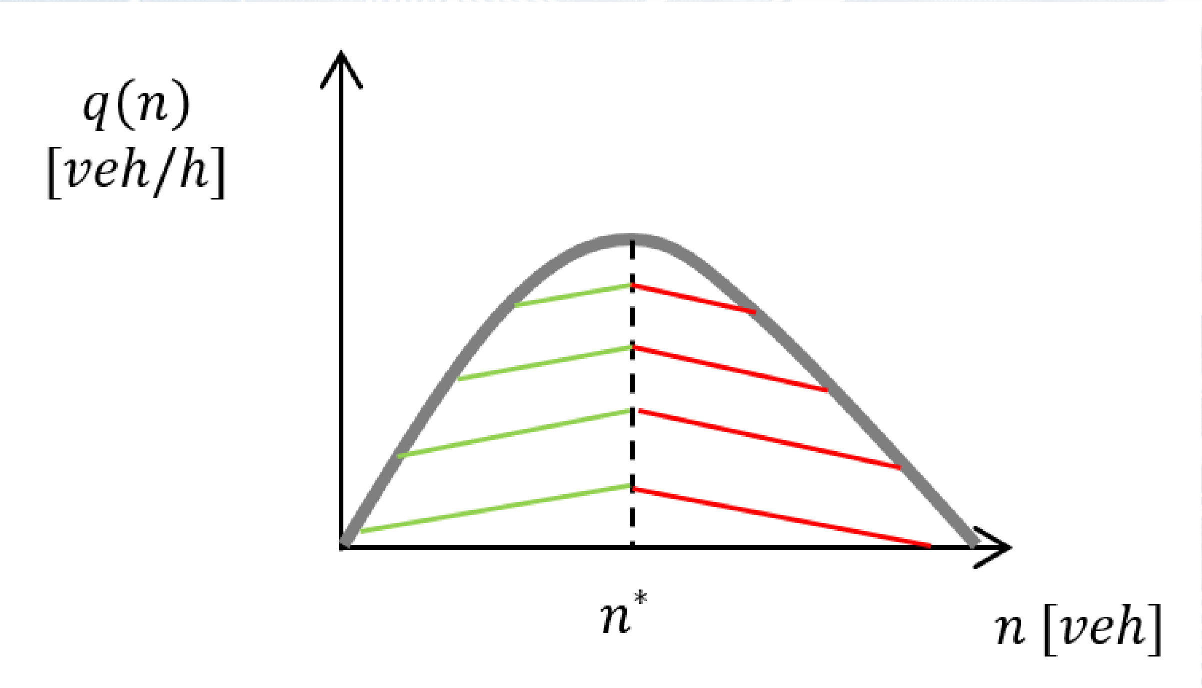
$$D = [d_{il}]_{N_{vehicles} \times K}\,,$$ → Avoid collision

$$\min(D) > d_{\min}$$ → Acceptable distance

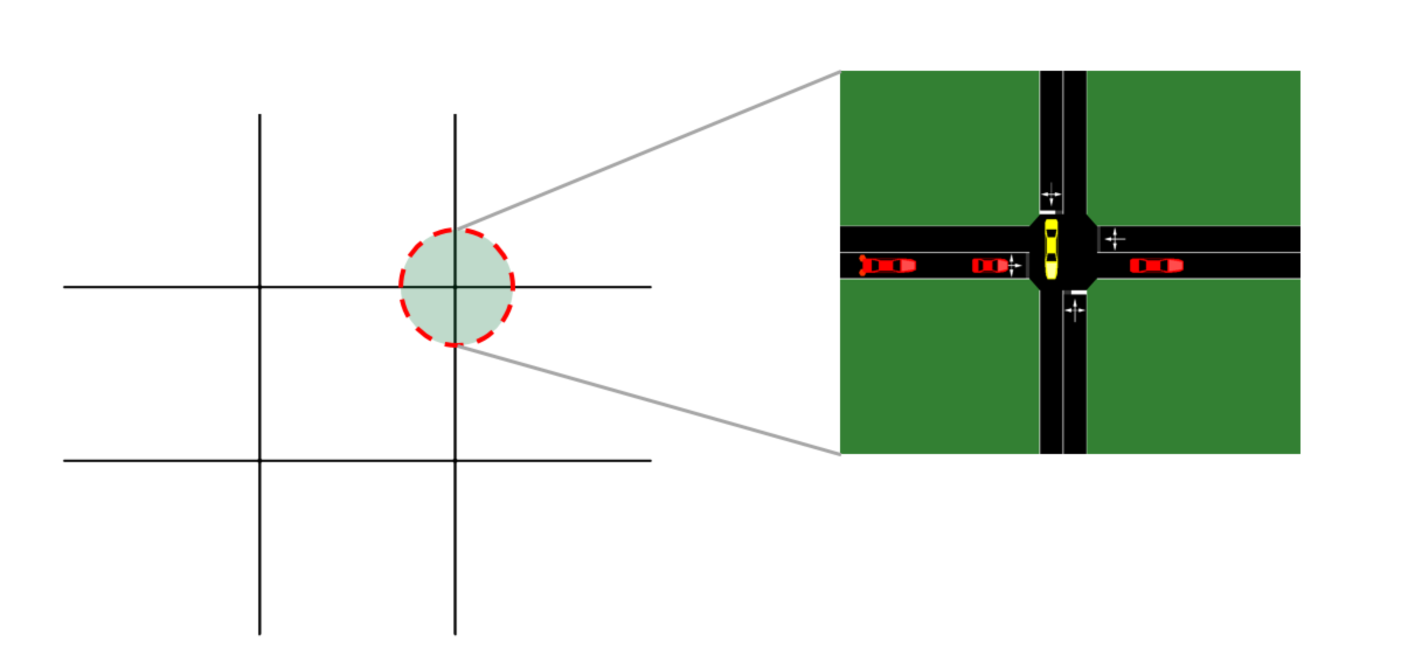
Macroscopic level control

Priority parameter is calculated based on the MFD model:

$$p_z = \begin{cases} 0, & n_z \leq n_z^* \\ \dfrac{n_z - n_z^*}{n_z^*}, & n_z > n_z^* \end{cases}$$



Simulations



MATLAB+SUMO (TraCI)   http://www.dlr.de/

Test network with 4 intersections

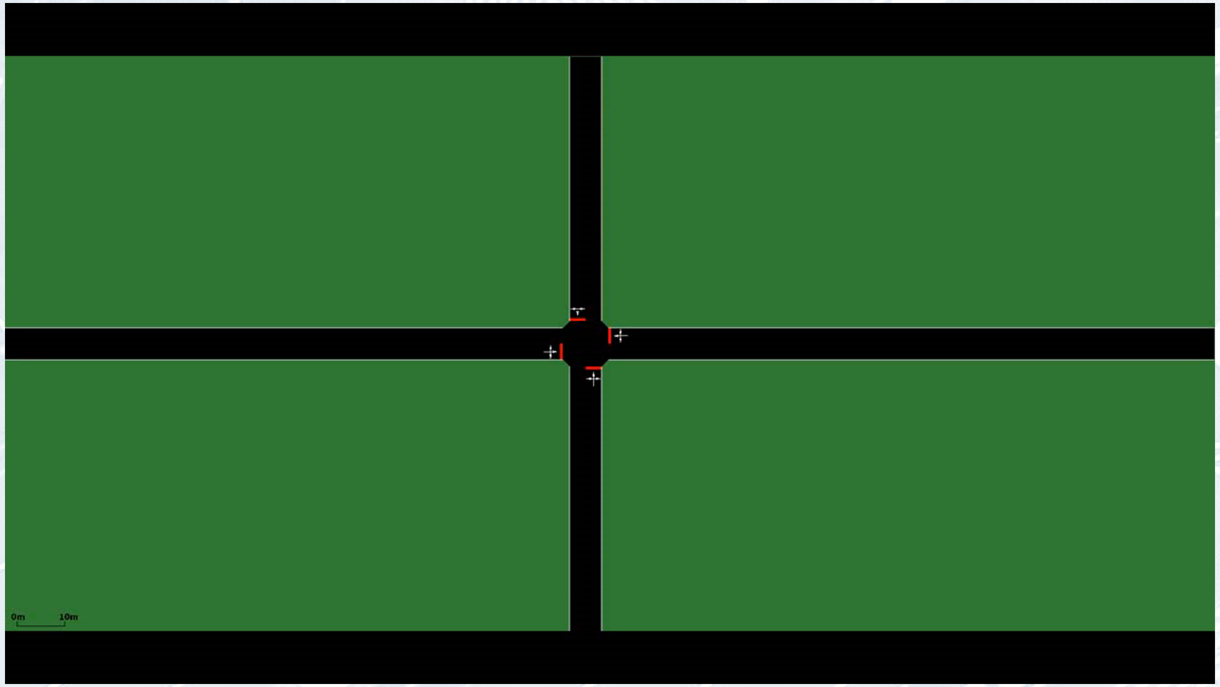
Prediction and control horizons = 20 seconds

MPC optimizer: nonlinear (fmincon)

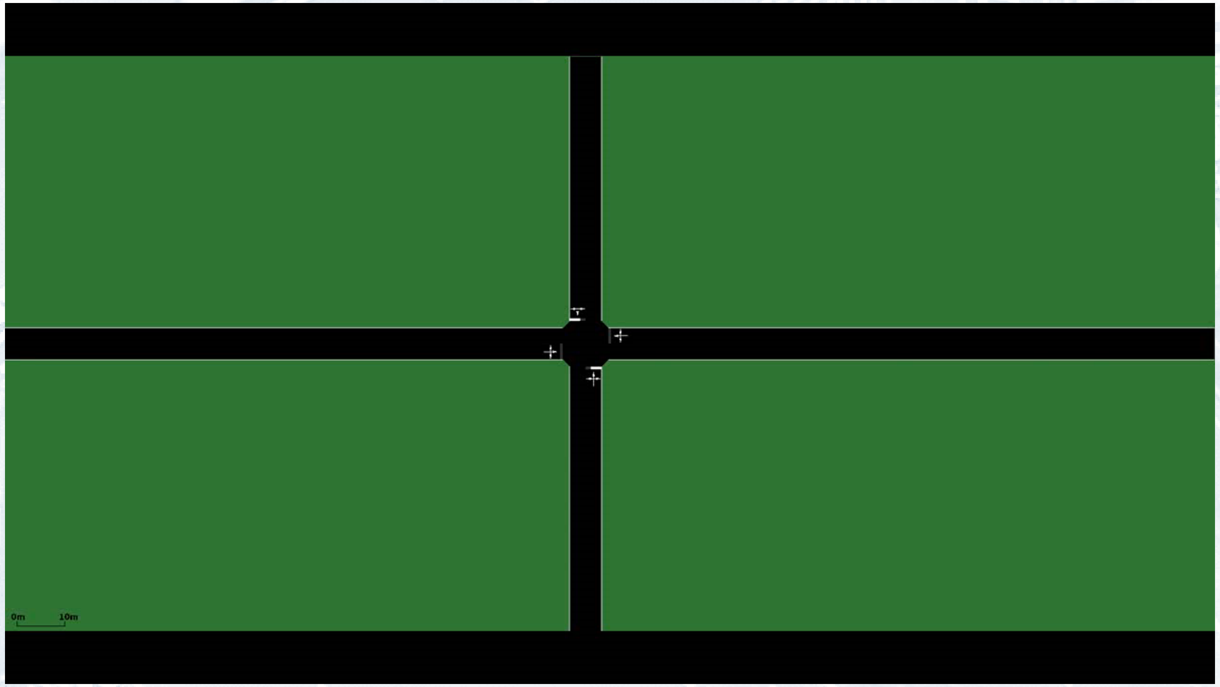
Visual results

Actuated

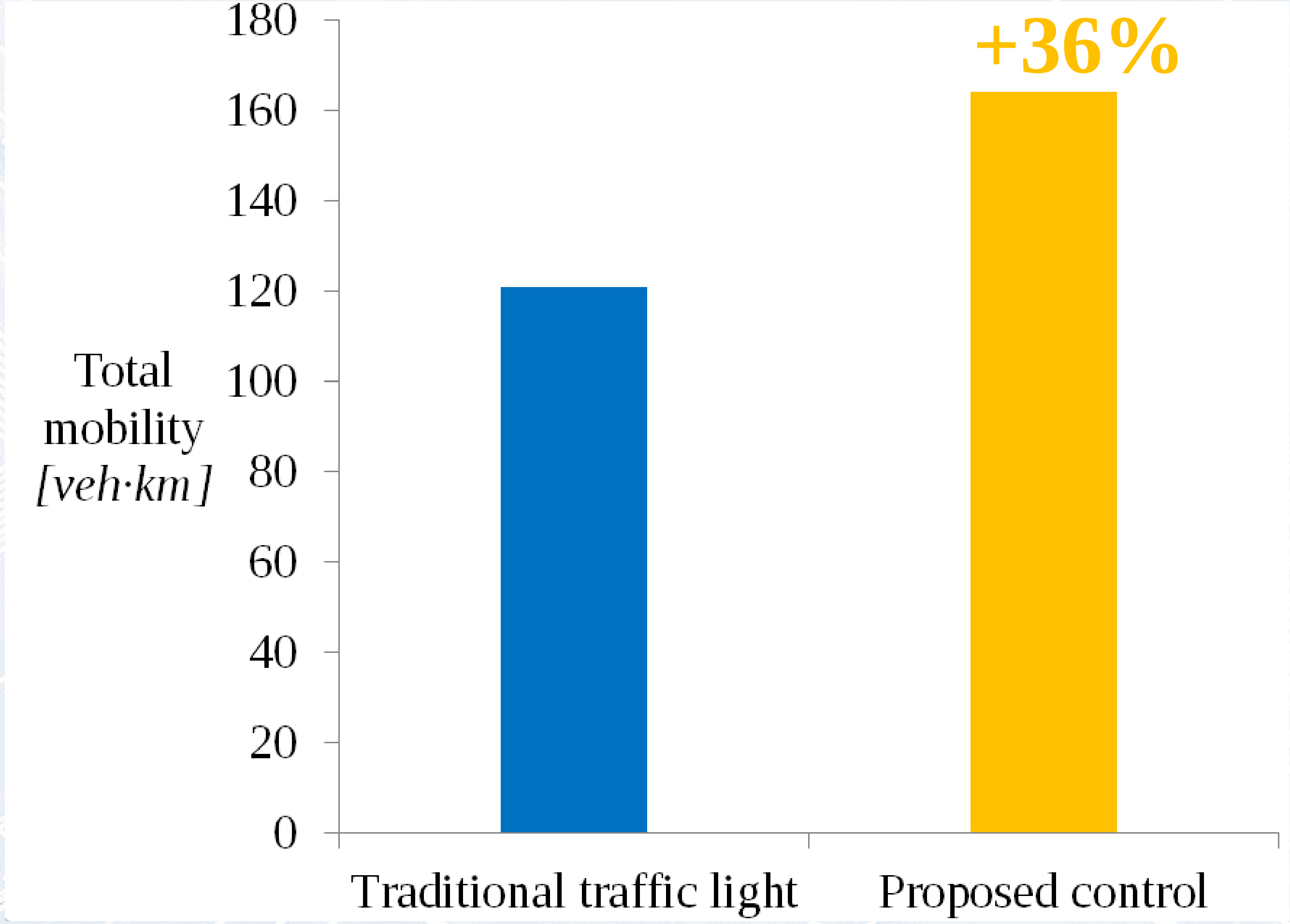
(time gap based actuated control)



Autonomous intersection control

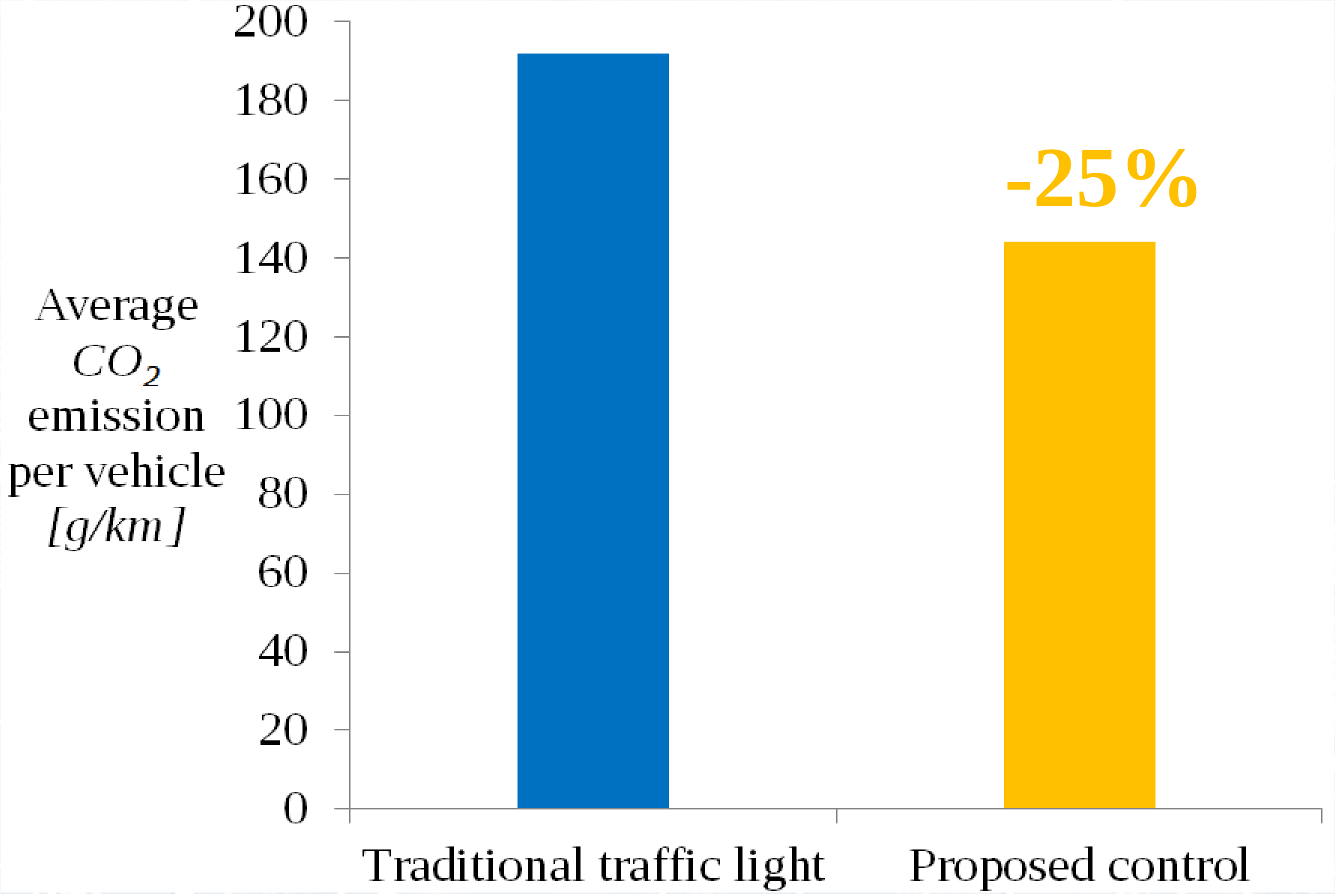


Results



The comparison of network mobility between the traditional and proposed methods.

Results



The comparison of CO_2 emission (based on HBEFA v3.1 data) between the traditional and proposed methods.

Conclusion and future work

- The performance of proposed control was justified:
  - High performance
  - Higher mobility
  - Lower emission

- Problems to overcome within the control design:
  - Disturbance can be present in the system, e.g. pedestrian crossing
  - Solution for the transition period (when traditional and autonomous cars are running together)

Thank you for your attention!!

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