Spatial and Transport Impacts of Automated Driving

MULTI-STAGE OPTIMIZATION OF ROAD NETWORKS FOR AUTOMATED DRIVING

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AUTOMATED DRIVING AND ROAD NETWORKS: AN INCREMENTAL APPROACH

https://www.traffictechnologytoday.com/features/futuristic-technologies-improving-roadways-now.html

omated_Driving

Source: https://oppmax.com/blog/state-self-driving-car-mid-2017-report/

Source: https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/

Source: https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/

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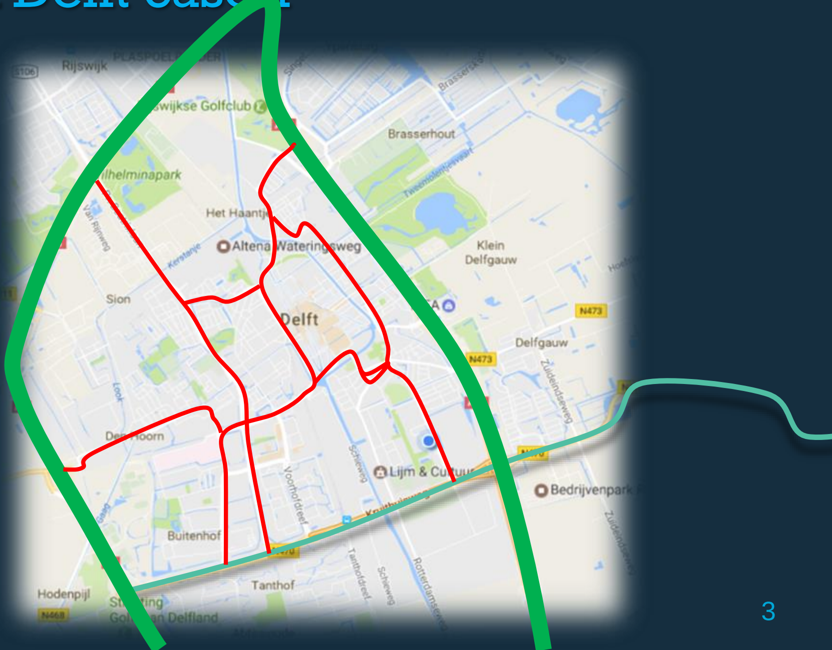
RESEARCH QUESTION

What are the possible network configurations for AVs?

(e.g., dedicated lanes, zones, links, everywhere)

We chose AD subnetworks: Delft case 1



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EXPLORING AD SUBNETWORKS

Purpose:

Macroscopic static TA & explore subnetwork concept

Methodology steps:

Subnetwork concept

Feasible road selection

Scenarios

Impacts

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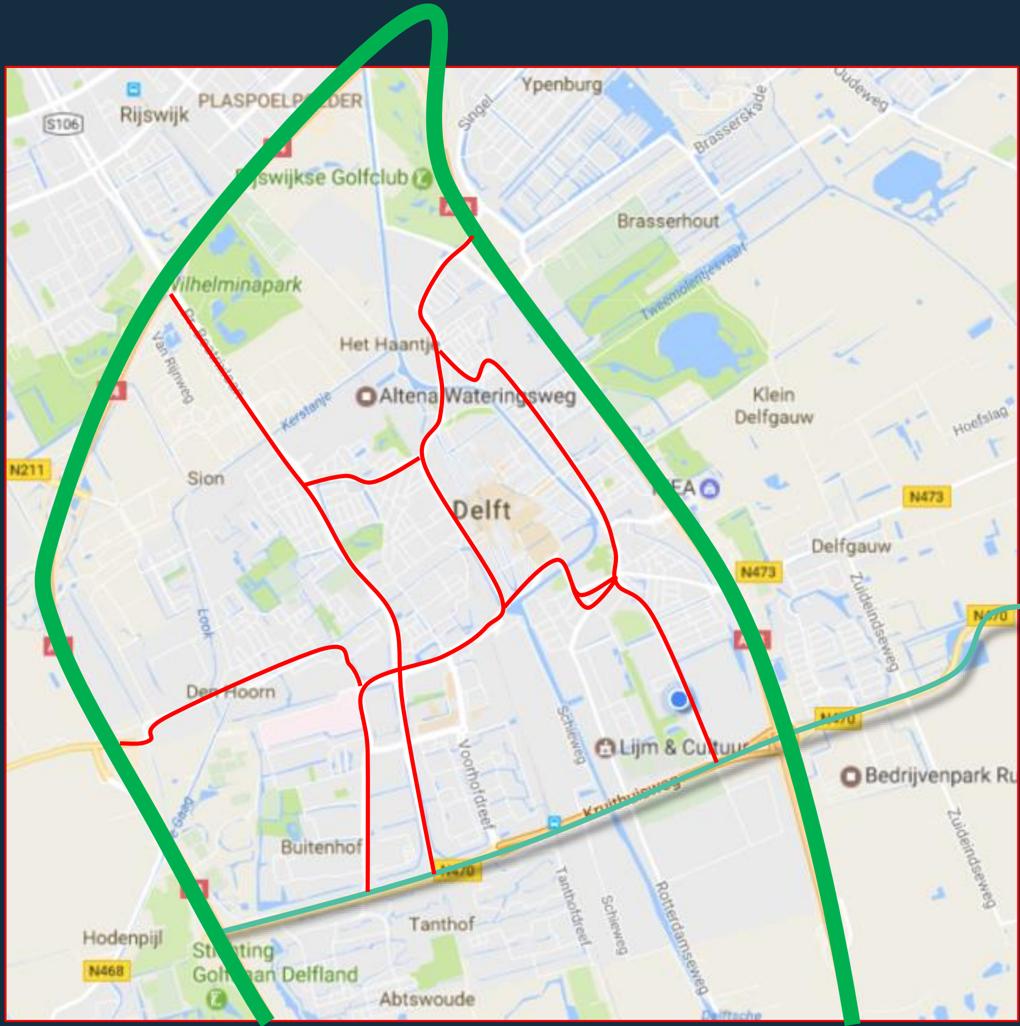
DELFT CASE 1:

INTRODUCING AD SUBNETWORKS

A priori link selection based on:

- ✓Road function
- ✓Potential quality
- ✓Traffic segregation
- ✓Complexity



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DELFT CASE 1:
INTRODUCING AD SUBNETWORKS

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INTRODUCING AD SUBNETWORKS: FORMULATION

Minimize

$$Z = \sum_{m} \frac{1}{\mu_m} \sum_{w\in W} \sum_{r\in R^w} F_m^{w,r} \ln F_m^{w,r} - \sum_{m} \frac{1}{\beta_m} \sum_{w\in W} \sum_{r\in R^w} F_m^{w,r} \ln PS_m^{w,r} + \sum_{m\in M} \sum_{a\in A} \int_0^{q_a} c_{m,a}(x)dx, \quad (1)$$

s.t.

$$q_a = \gamma_0(f_{0,a} + f_{1,a}), \quad \forall\, a \in A_0, \quad (2)$$

$$q_a = \gamma_0 f_{0,a} + \gamma_1 f_{1,a}, \quad \forall\, a \in A_1, \quad (3)$$

$$\sum_{r\in R^w} F_m^{w,r} = D_m^w, \quad \forall\, w \in W, \forall\, m \in M, \quad (4)$$

$$\sum_{w\in W} \sum_{r\in R^w} F_m^{w,r} \delta_{m,a}^{w,r} = f_{m,a}, \quad \forall\, a \in A, \forall\, m \in M, \quad (5)$$

$$F_m^{w,r} \geqslant 0, \quad \forall\, w \in W, \forall\, m \in M, \forall\, r \in R^w. \quad (6)$$

$$t_a(q_a) = t_a^0 \left[1 + \alpha_a \left(\frac{q_a}{\Lambda_a}\right)^{b_a}\right]. \quad (7)$$

And link cost per class is:

$$c_{0,a}(q_a) = \theta_0 l_a + \eta_0 t_a(q_a) \;, \; \forall\, a \in A, \quad (8)$$

$$c_{1,a}(q_a) = \theta_0 l_a + \eta_0 t_a(q_a) \;, \; \forall\, a \in A_0, \quad (9)$$

$$c_{1,a}(q_a) = \theta_1 l_a + \eta_1 t_a(q_a) \;, \; \forall\, a \in A_1. \quad (10)$$

$$P_m^{w,r} = \frac{\exp(-\mu_m C_m^{w,r} + \beta_m \ln PS_m^{w,r})}{\sum_{r\in R^w} \exp(-\mu_m C_m^{w,r} + \beta_m \ln PS_m^{w,r})}, \; \forall\, w \in W, \forall\, m \in M, \forall\, r \in R^w, \quad (11)$$

where path-size penalty is defined as:

$$PS_m^{w,r} = \sum_{a\in r} \left(\frac{l_a}{l_r}\right)\left(\frac{1}{\sum_{r\in R^w} \delta_{m,a}^{w,r}}\right), \quad (12)$$

and route-based travel cost (generalized travel cost) for two classes are given as:

$$C_0^{w,r} = \sum_{a\in A} \delta_{0,a}^{w,r} F_0^{w,r} (\theta_0 l_a + \eta_0 t_a(q_a)), \quad (13)$$

$$C_1^{w,r} = \sum_{a\in A_0} \delta_{1,a}^{w,r} F_1^{w,r} (\theta_0 l_a + \eta_0 t_a(q_a)) + \sum_{a\in A_1} \delta_{1,a}^{w,r} F_1^{w,r} (\theta_1 l_a + \eta_1 t_a(q_a)). \quad (14)$$

$$TTC = \sum_{a\in A_0} (\eta_0 \bar{t}_a + \theta_0 l_a)(\bar{f}_{0,a} + \bar{f}_{1,a}) + \sum_{a\in A_1} [(\eta_0 \bar{t}_a + \theta_0 l_a)\bar{f}_{0,a} + (\eta_1 \bar{t}_a + \theta_1 l_a)\bar{f}_{1,a}], \quad (15)$$

$$TTT = \sum_{a\in A} \bar{t}_a(\bar{f}_{0,a} + \bar{f}_{1,a}), \quad (16)$$

$$TTD = \sum_{a\in A} l_a(\bar{f}_{0,a} + \bar{f}_{1,a}). \quad (17)$$

DELFT CASE 1: INTRODUCING AD SUBNETWORKS (SUMMARY)

Scenarios:

3 (5) subnetworks & 5 (7) demand scenarios

Impacts:

TTC, TTT, TTD & distribution in different road types

Sensitivity analysis:

TA AV parameters

Conclusion:

Optimizing trade-offs between costs and benefits

RESEARCH QUESTION

How can we optimize this configuration (selection)?

Delft case 2: Optimizing urban road networks for AD

(a) Road types

(b) Feasible roads for AD subnetwork

OPTIMIZING URBAN ROAD NETWORKS FOR AD

Purpose:

Define optimization problem, solutions, future extensions

Methodology:

Formulate a bi-level optimization problem

Find (develop) solution methods & measure performance

Find methodology shortcomings & best extensions (future steps)

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OPTIMIZING URBAN ROAD NETWORKS FOR AD: FORMULATION

LLMP:

$$\min_{f_{m,a}} \quad Z_L = \sum_m \frac{1}{\mu_m}\sum_{w\in W}\sum_{r\in R^w} F_m^{w,r}\ln F_m^{w,r} - \sum_m \frac{1}{\beta_m}\sum_{w\in W}\sum_{r\in R^w} F_m^{w,r}\ln PS_m^{w,r}$$
$$+\sum_{m\in M}\sum_{a\in A_0}\int_0^{q_a}\theta_0 l_a+\eta_0 t_a(x)dx$$
$$+\sum_{a\in A_1}\int_0^{q_a}\theta_0 l_a+\eta_0 t_a(x)dx+\sum_{a\in A_1}\int_0^{q_a}\theta_1 l_a+\eta_1 t_a(x)dx \qquad (1)$$

s.t.

$$q_a=\gamma_0(f_{0,a}+f_{1,a}) \qquad ,\forall a\in A_0 \qquad (2)$$
$$q_a=\gamma_0 f_{0,a}+\gamma_1 f_{1,a} \qquad ,\forall a\in A_1 \qquad (3)$$
$$t_a(q_a)=t_a^0[1+\alpha_a(\frac{q_a}{\Lambda_a})^{b_a}] \qquad ,\forall a\in A \qquad (4)$$
$$\sum_{r\in R^w} F_m^{w,r}=D_m^w \qquad ,\forall w\in W,\forall m\in M \qquad (5)$$
$$\sum_{w\in W}\sum_{r\in R^w} F_m^{w,r}\delta_{m,a}^{w,r}=f_{m,a} \qquad ,\forall a\in A,\forall m\in M \qquad (6)$$
$$F_m^{w,r}\geq 0 \qquad ,\forall w\in W,\forall m\in M,\forall r\in R^w \qquad (7)$$
$$PS_m^{w,r}=\sum_{a\in r}(\frac{l_a}{l_r})(\frac{1}{\sum_{r\in R^w}\delta_{m,a}^{w,r}}), \qquad ,\forall w\in W,\forall m\in M,\forall r\in R^w \qquad (8)$$

ULMP:

$$\min_{I_a} \quad Z_u=TTC(I_a)+\frac{TAC(I_a)}{\sigma}, \qquad (9)$$

s.t.

$$TTC(I_a)=\sum_{a\in A}\{(1-I_a)[(\eta_0\bar{t}_a+\theta_0 l_a)(\bar{f}_{0,a}+\bar{f}_{1,a})]$$
$$+I_a[(\eta_0\bar{t}_a+\theta_0 l_a)\bar{f}_{0,a}+(\eta_1\bar{t}_a+\theta_1 l_a)\bar{f}_{1,a}]\} \qquad (10)$$
$$TAC(I_a)=\sum_{a\in A} I_a ac_a \qquad (11)$$
$$I_a(1-I_a)=0 \qquad ,\forall a\in A \qquad (12)$$
$$\left|p_{\hat{G}_1}^{s,t}\right|\geq 1 \qquad ,\forall s,t\in N_1 \qquad (13)$$

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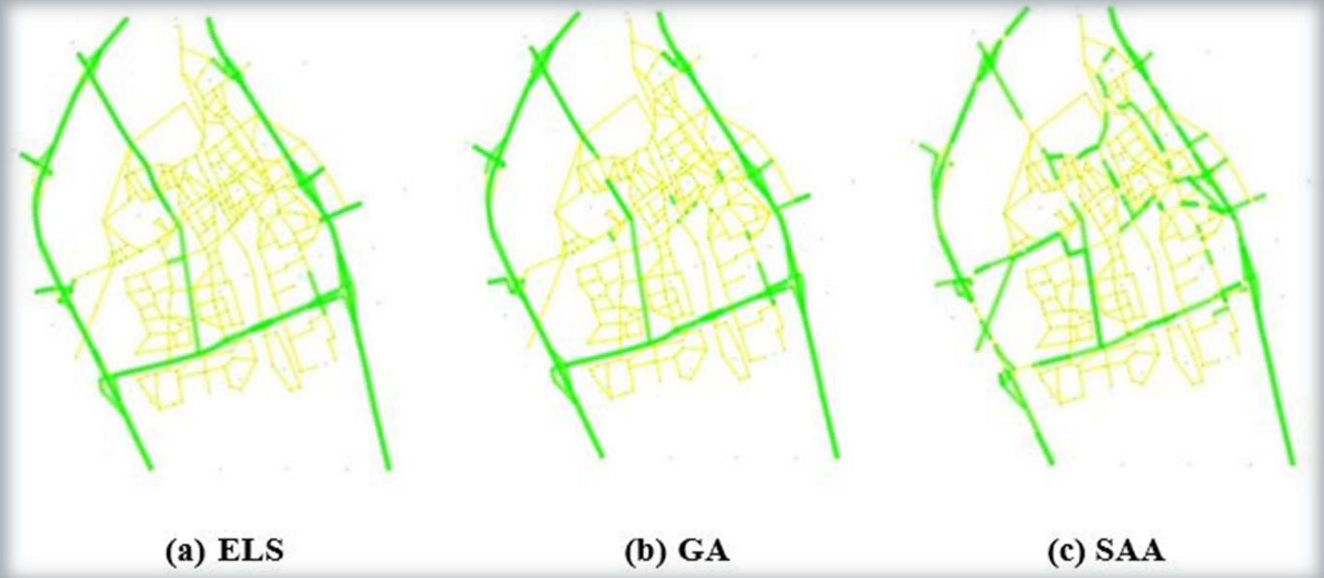
DELFT CASE 2: LESSONS LEARNED

Disconnected Subnetworks!



DELFT CASE 2: LESSONS LEARNED

Disconnected Subnetworks!

(a) ELS (b) GA (c) MGA

DELFT CASE 2: LESSONS LEARNED

Dependency on adjustment cost and demand

10% high cost

90% low cost

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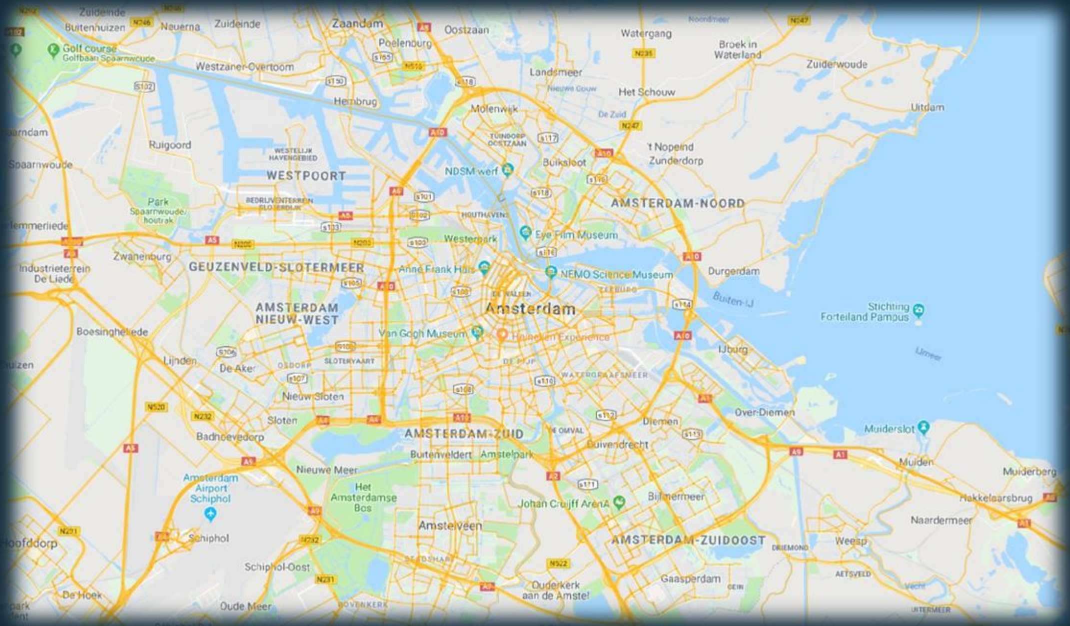
RESEARCH QUESTION

What is the optimal order and timing for the adjustments?

Amsterdam case study 1



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MULTI-STAGE OPTIMIZATION OF ROAD NETWORKS FOR AUTOMATED DRIVING

Purpose:

Tri-level optimization problem

Can we solve this for a realistic network?

Behavioral (transport-related) insights from case study

Methodology:

Formulate the optimization problem

Find (develop) solution methods & measure performance

Analyze results

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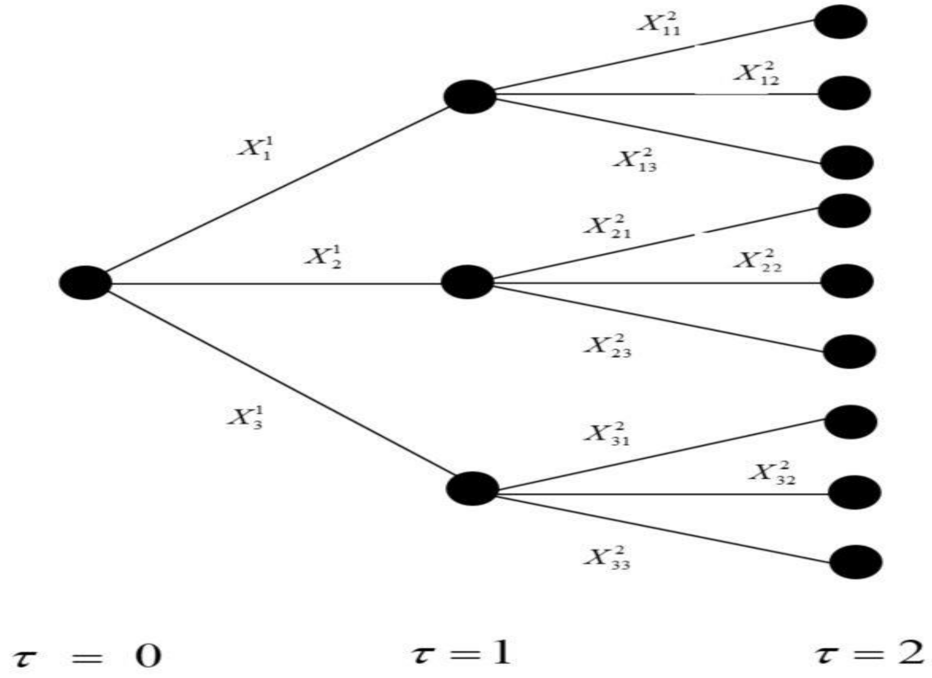
Upper level decision choice tree



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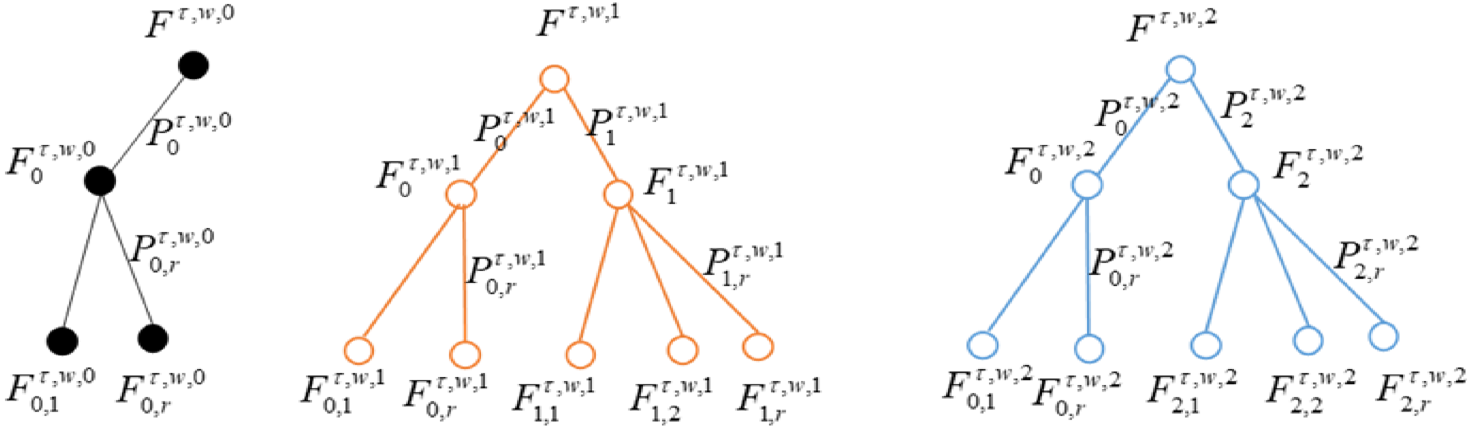
Lower level decision choice tree



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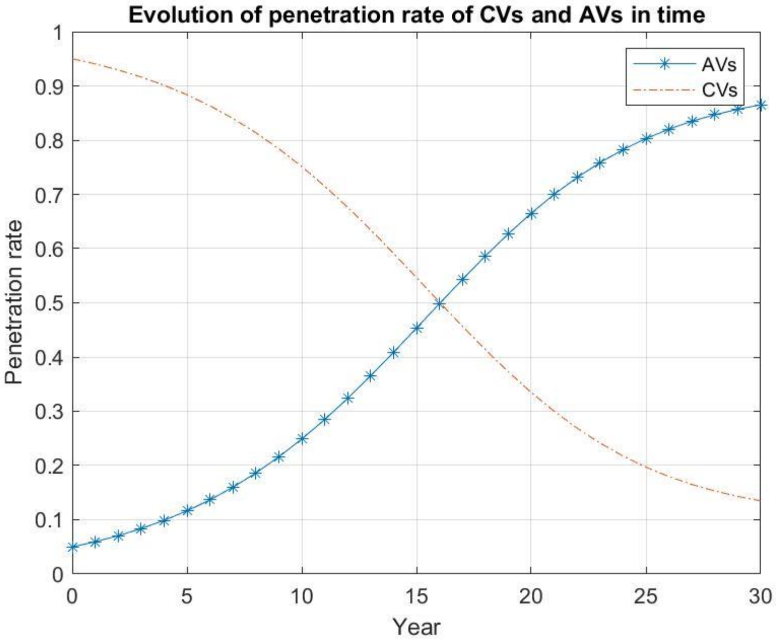
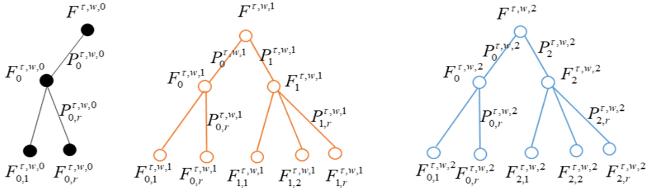
AV Diffusion model





AMSTERDAM CASE STUDY (VENOM MODEL)

52,810 links
10,124 OD pairs

Several municipalities

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AMSTERDAM CASE STUDY

52,810 links in the network (52,810 lower level decision variables)

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AMSTERDAM CASE STUDY

5801 feasible links (2^{5804} combinations for upper level solution)

AMSTERDAM CASE STUDY: UPPER LEVEL SOLUTION ALGORITHMS

GA	EPS	EGS
Out of the box	Adapted	Novel
Augmented time	Tailored	Fully tailored
Connectivity penalty		

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AMSTERDAM CASE 1:
LESSONS LEARNED

Evolution of networks and connectivity

t = 0

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AMSTERDAM CASE 1:
LESSONS LEARNED

Evolution of networks and connectivity

t = 0

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AMSTERDAM CASE 1:
LESSONS LEARNED

More cars and increased TT!
Shift towards the main roads

Before

After

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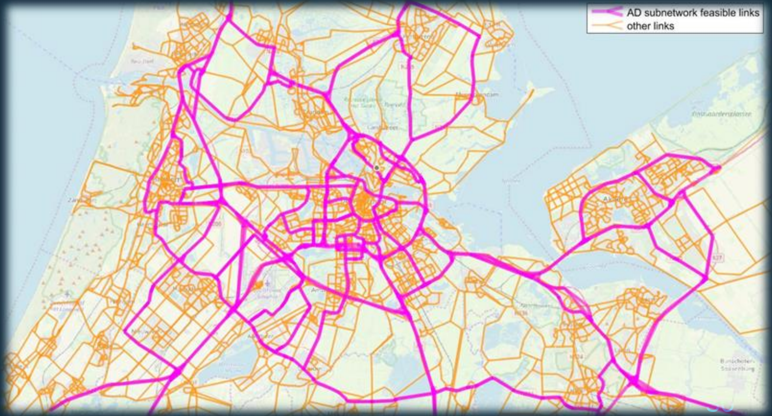
AMSTERDAM CASE 1:

To do:
Distribution of accessibility and mode choice

Demand supply interactions: proactive v.s. reactive
Waiting for the demand or provoking it?



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QUESTIONS?

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