



Green Cooperative Intersection

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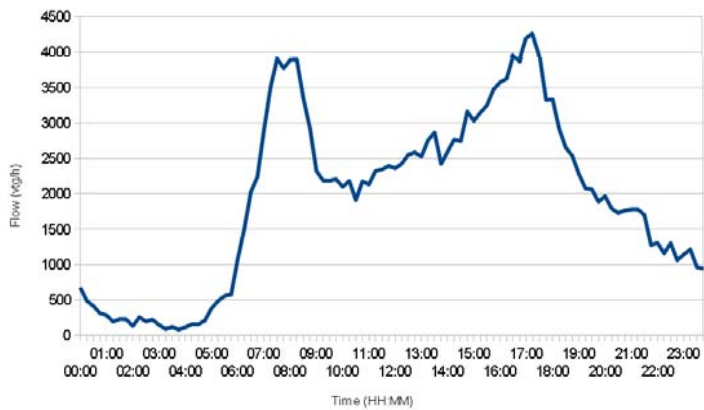
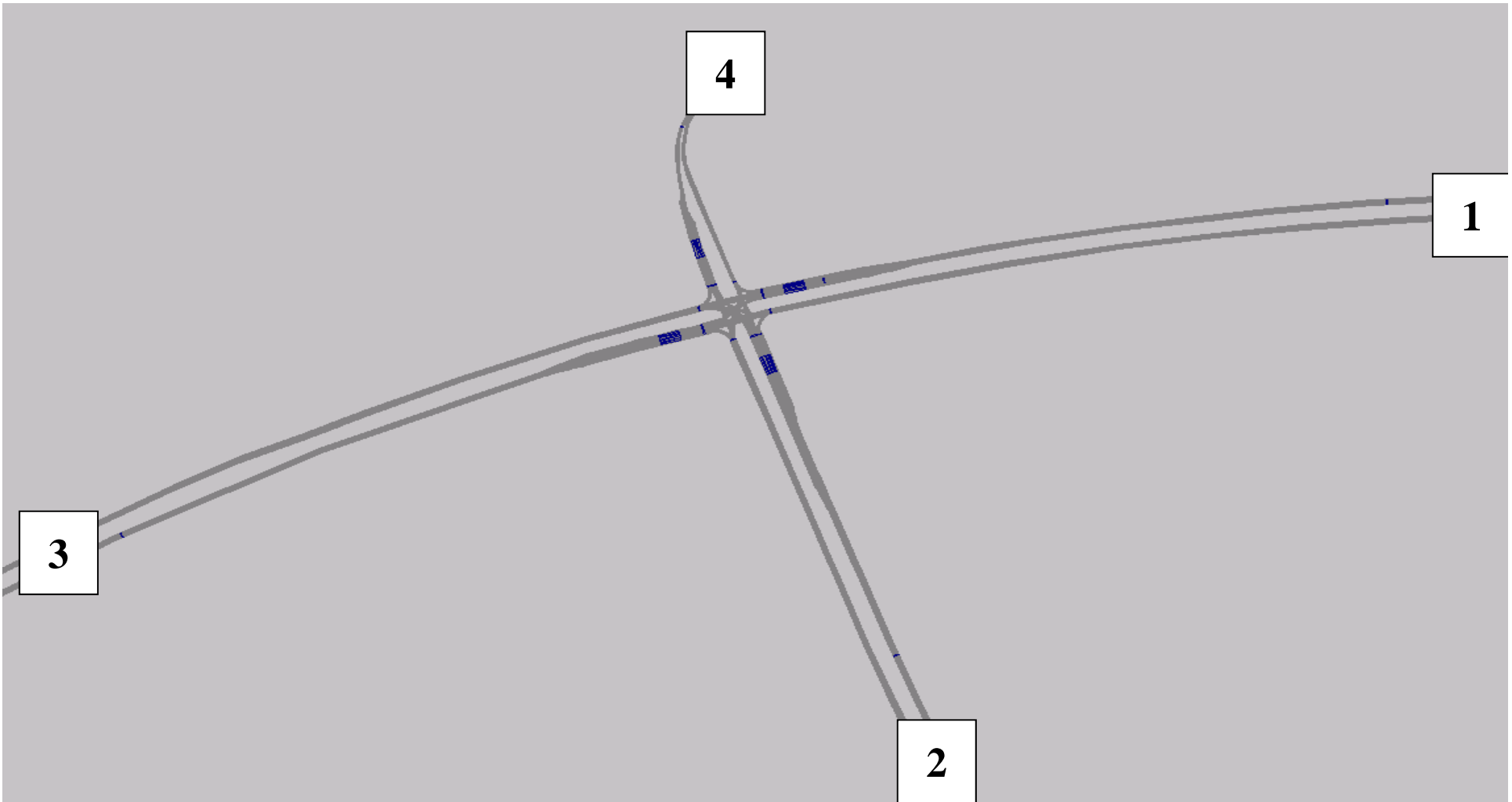


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Contents

- Illustrating the concept for a single intersection
 - Introduction of the intersection
 - Improving the baseline
 - CO₂ emission minimization
 - Through ecoBalanced Priority
 - Through ecoApproach Advice
- Concepts applied in a larger network (Robbin)



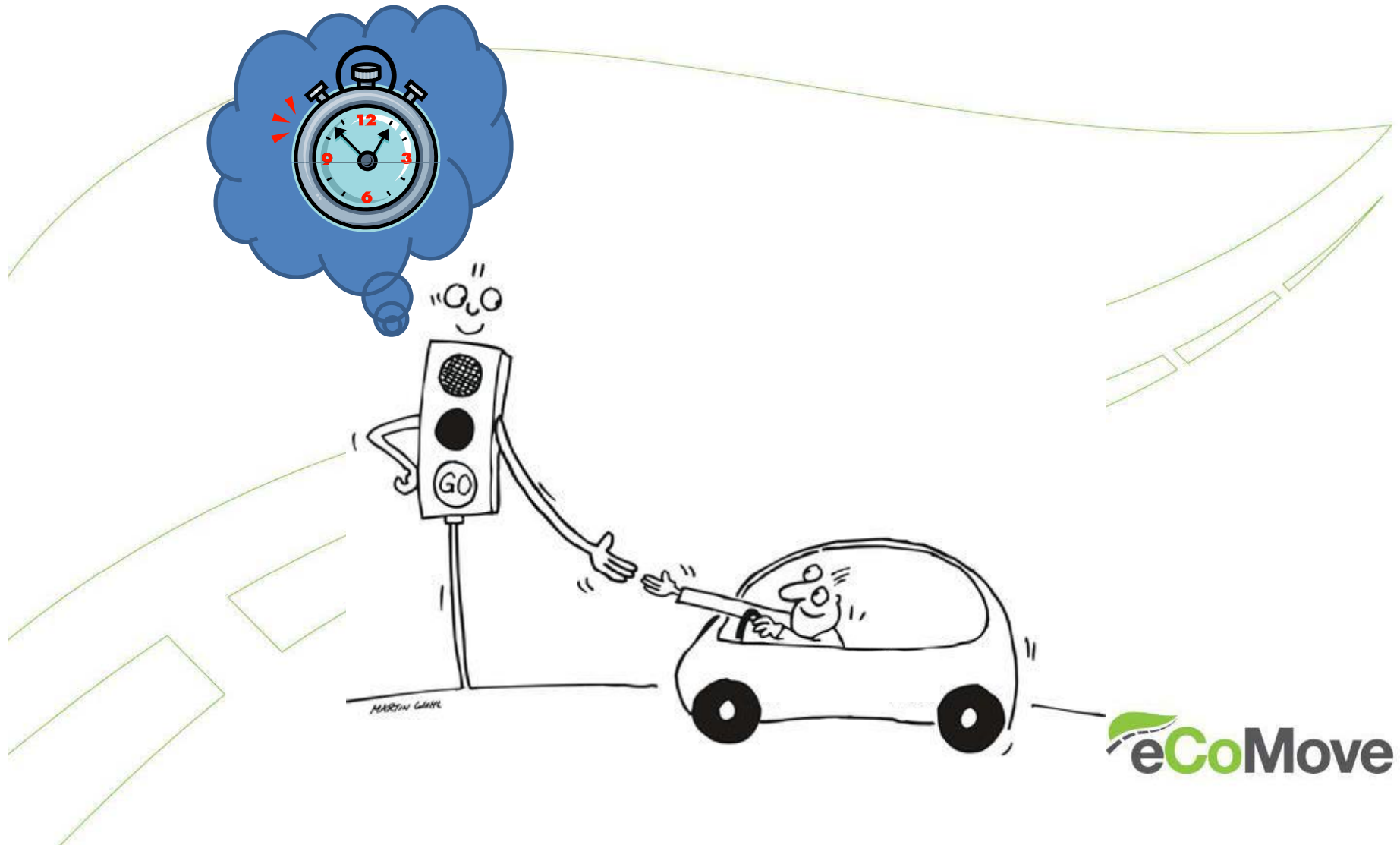
	1	2	3	4	Total
1	0	68	1125	0	1193
2	110	0	762	88	960
3	692	185	0	136	1013
4	1	64	293	0	358
Total	803	317	2180	224	3524

Totals for peak hour (07:00-08:00)

	1	2	3	4	Total
1	0	89	741	0	830
2	121	0	226	66	413
3	721	227	0	98	1046
4	2	67	126	0	195
Total	844	383	1093	164	2484

Totals for off-peak hour (12:00-13:00)

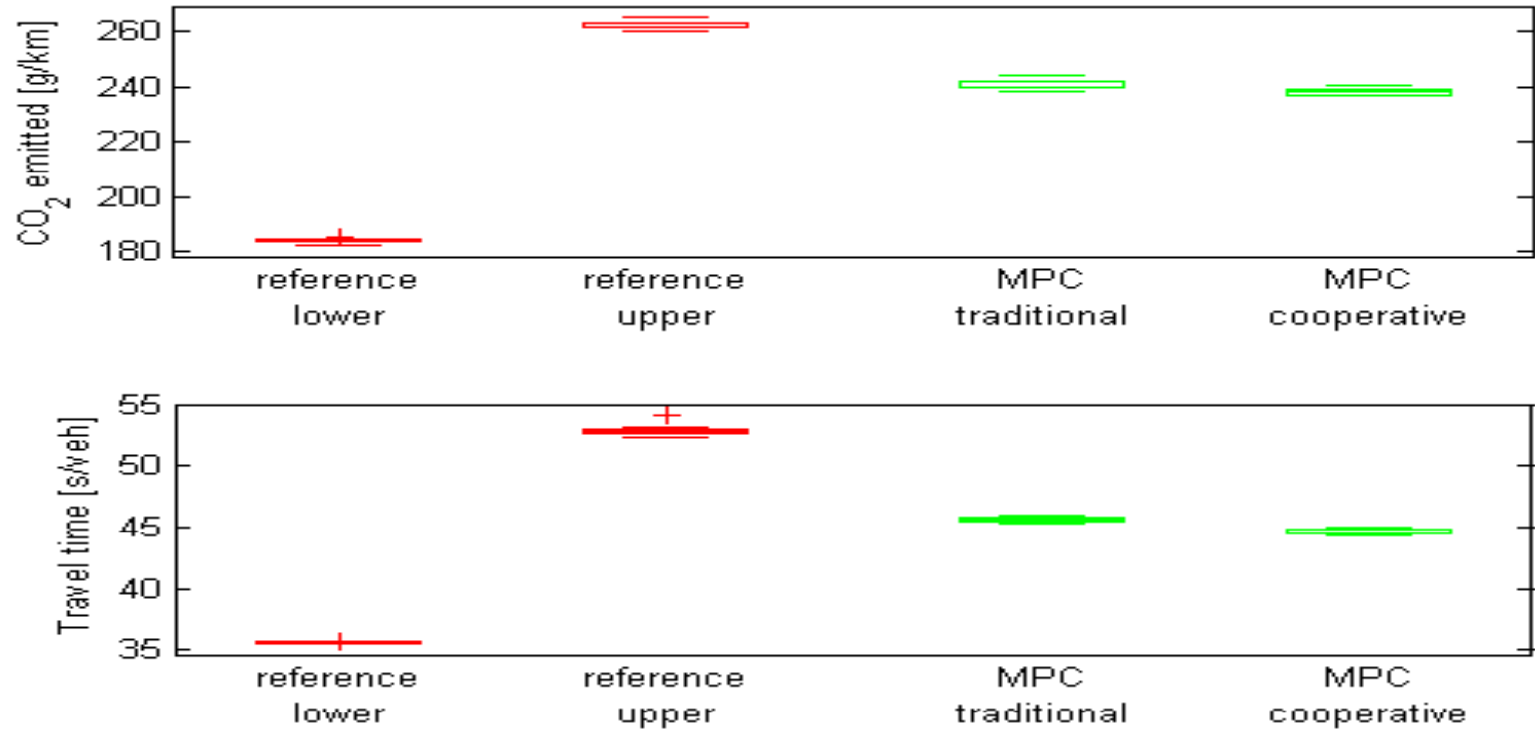
Improving the baseline



Improving the baseline

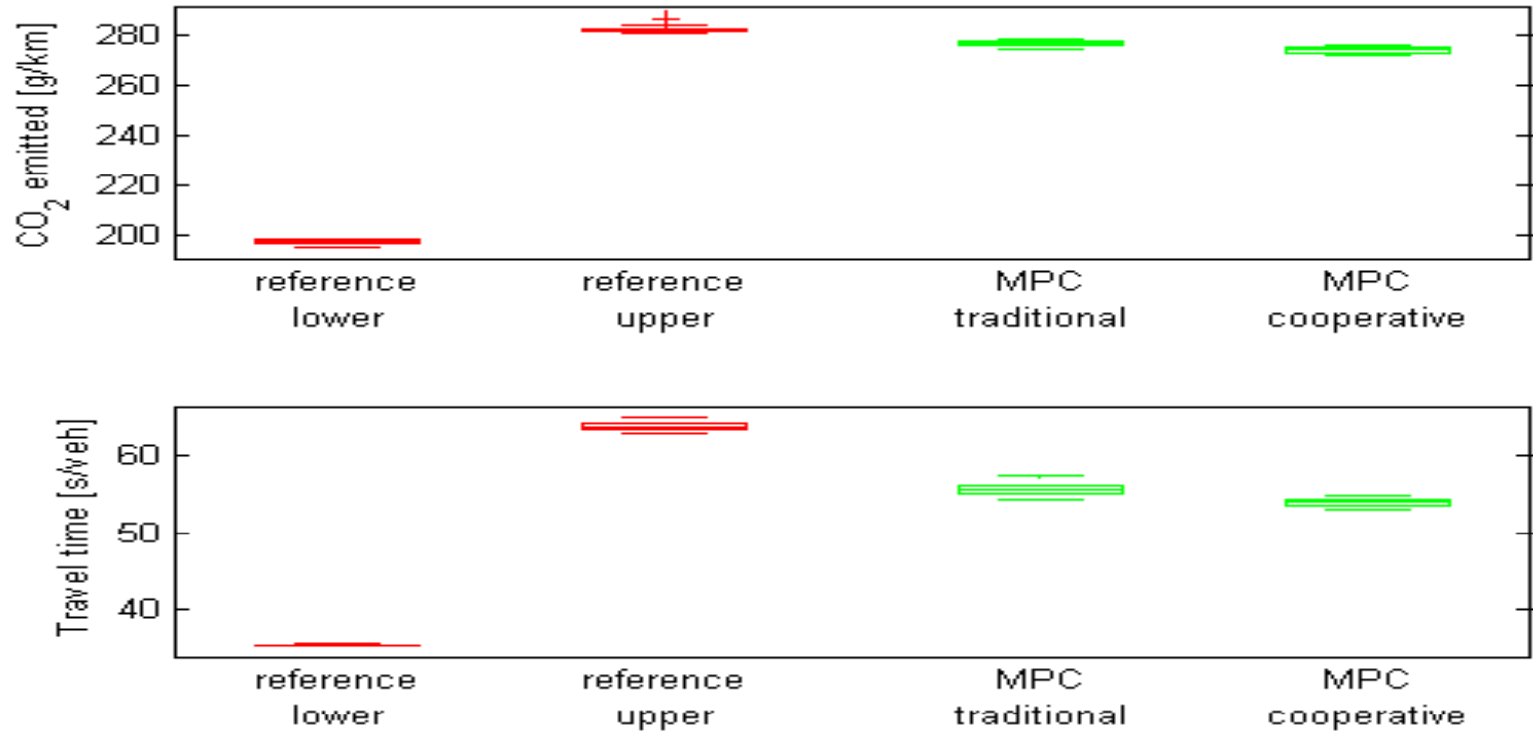
- Using a Model Predictive Control (MPC) approach
- Using supplementary information from the vehicle, such as the desired turn

Off-peak hour results



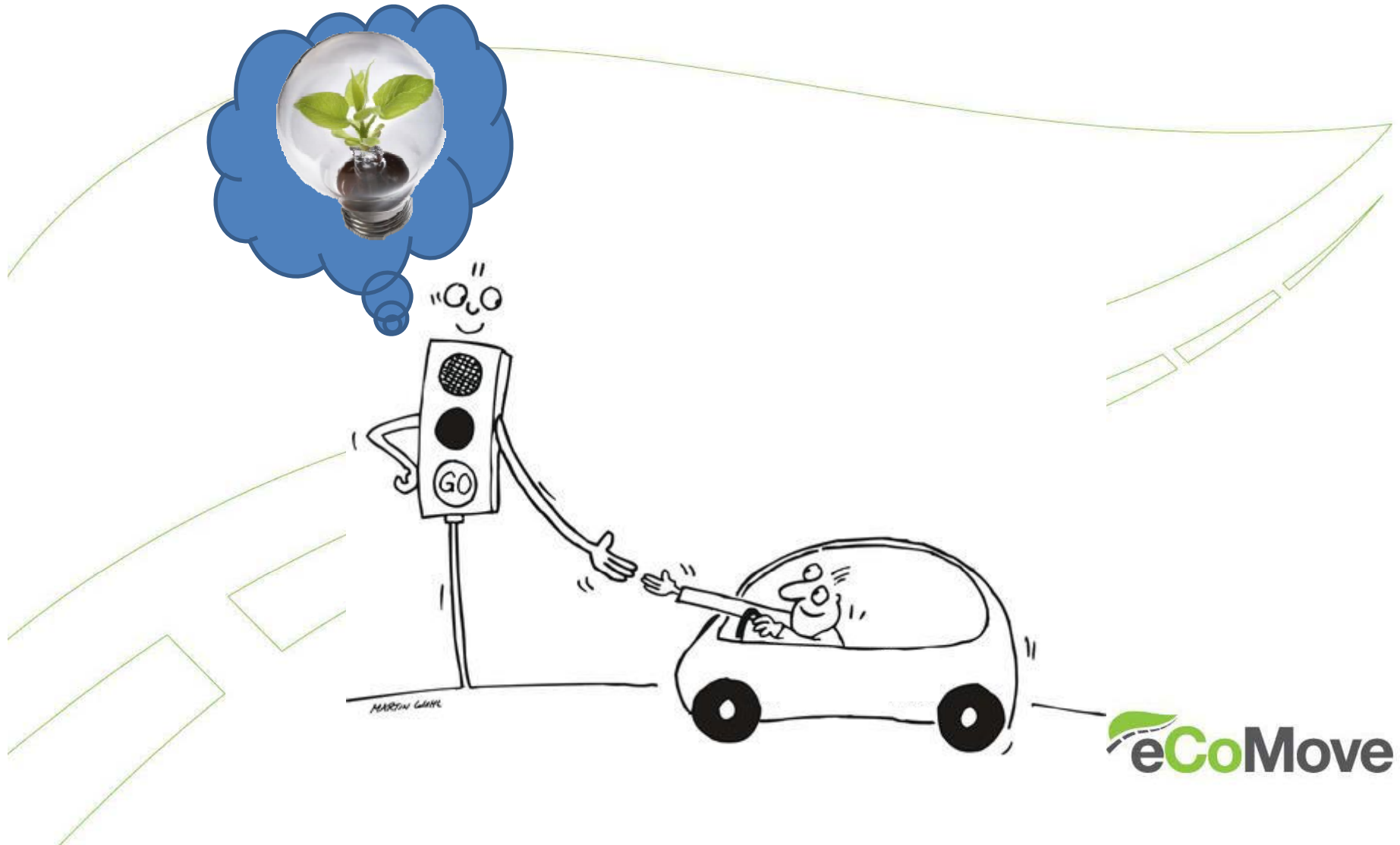
Controller	Detection	Improvements w.r.t. Traffic-Actuated control		Improvements w.r.t. Model Predictive Control	
		CO ₂ (g/veh)	Travel Time (s/veh)	CO ₂ (g/veh)	Travel Time (s/veh)
Conflictfree	traditional	30,1%	32,6%	23,7%	21,9%
Actuated	traditional	N/A	N/A	-9,1%	-16,0%
MPC	traditional	8,3%	13,8%	N/A	N/A
MPC	cooperative	9,3%	15,4%	1,0%	1,9%

Peak hour results



Controller	Detection	Improvements w.r.t. Traffic-Actuated control		Improvements w.r.t. Model Predictive Control	
		CO ₂ (g/veh)	Travel Time (s/veh)	CO ₂ (g/veh)	Travel Time (s/veh)
Conflictfree	traditional	29,9%	44,4%	28,5%	36,3%
Actuated	traditional	N/A	N/A	-2,1%	-14,7%
MPC	traditional	2,0%	12,8%	N/A	N/A
MPC	cooperative	2,9%	15,5%	0,9%	3,1%

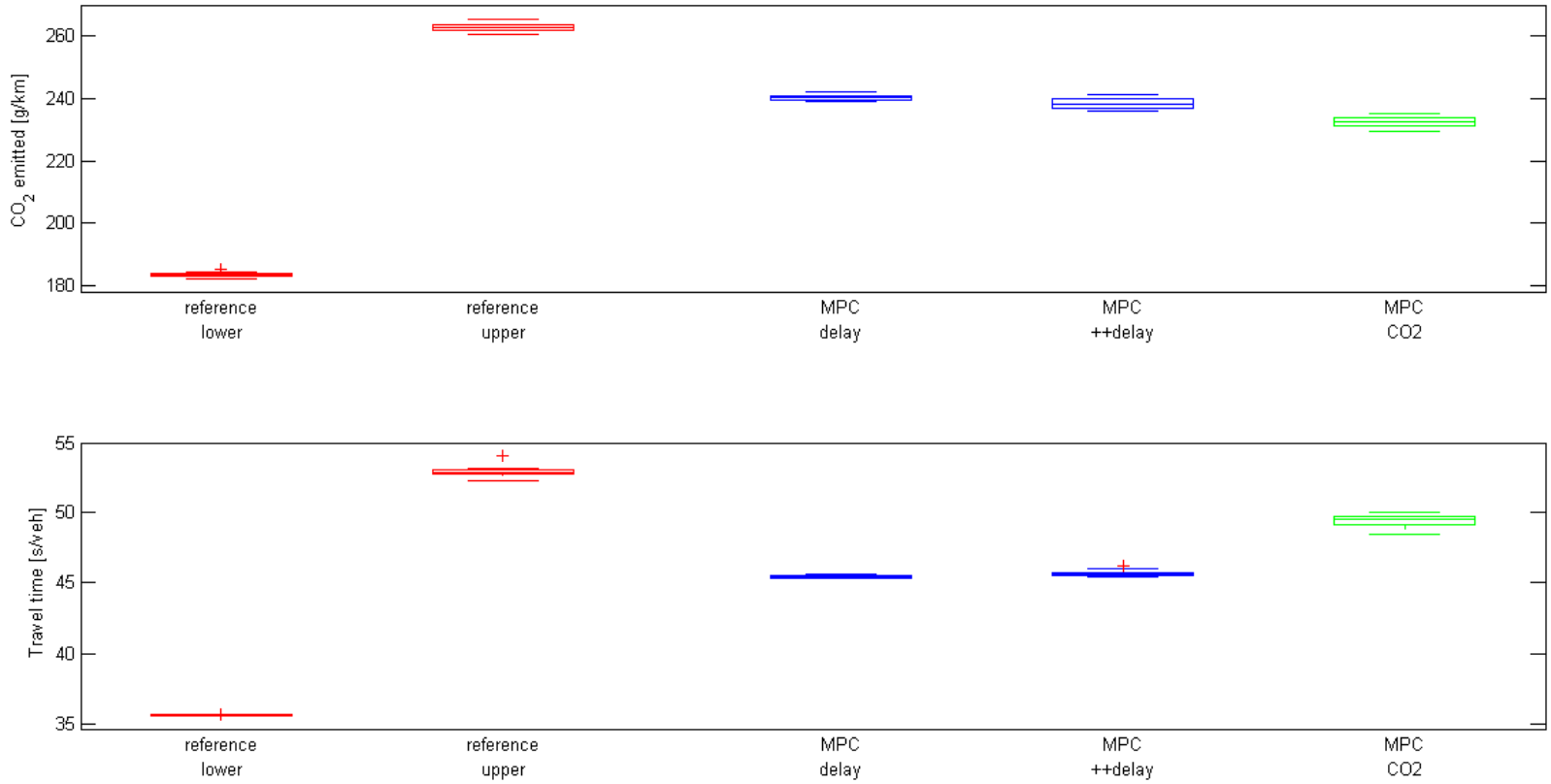
Emission minimization: eCoBalanced Priority



Emission minimization: eCoBalancedPriority

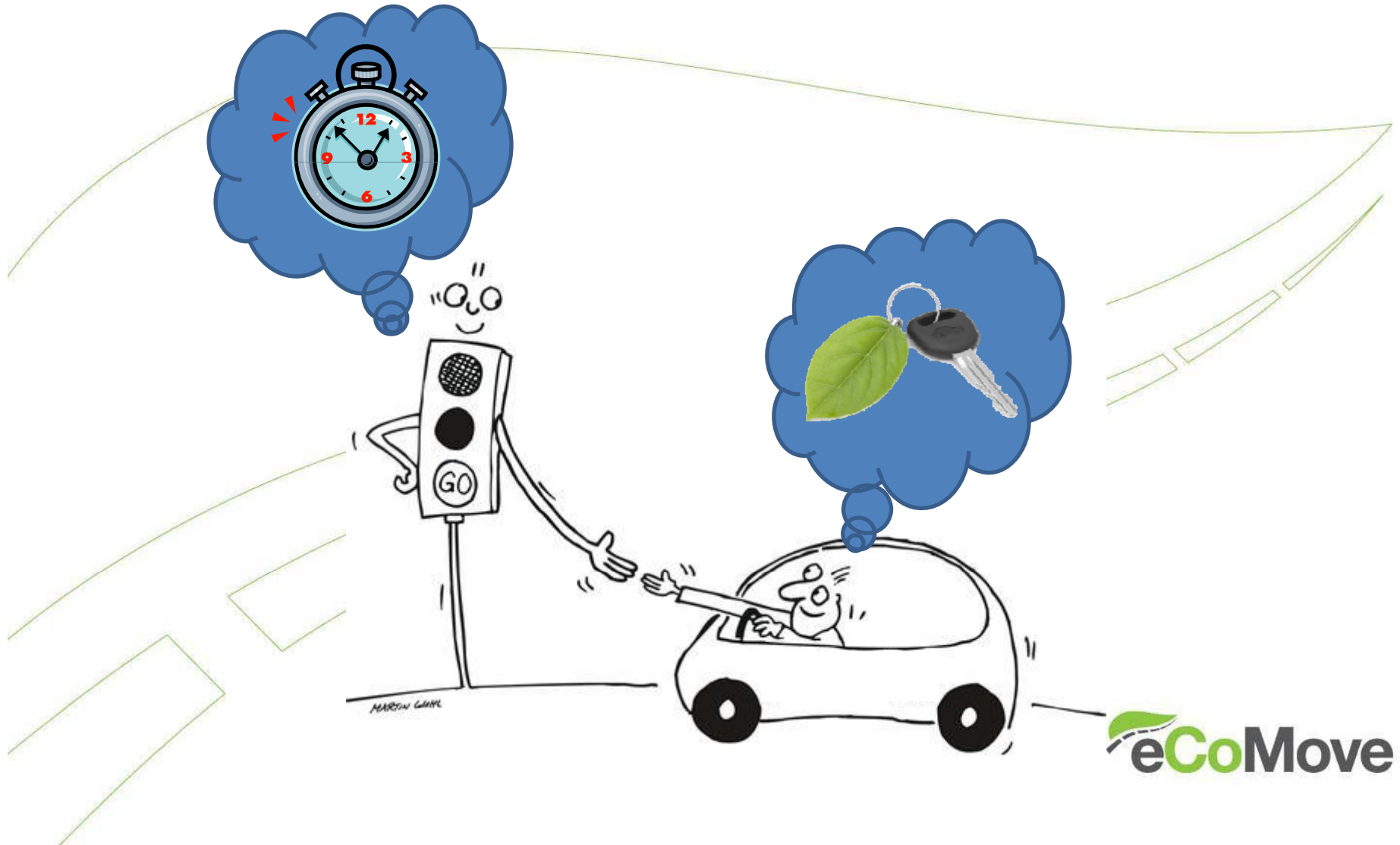
- Using supplementary information from the vehicle, such as the vehicle type
- Taking into account that delay comes in flavours with different emission characteristics, i.e.
 - Deceleration delay
 - Idling delay
 - Acceleration delay
- Taking into account that most emissions occur after the stop line instead of before the stop line

Off-peak hour results

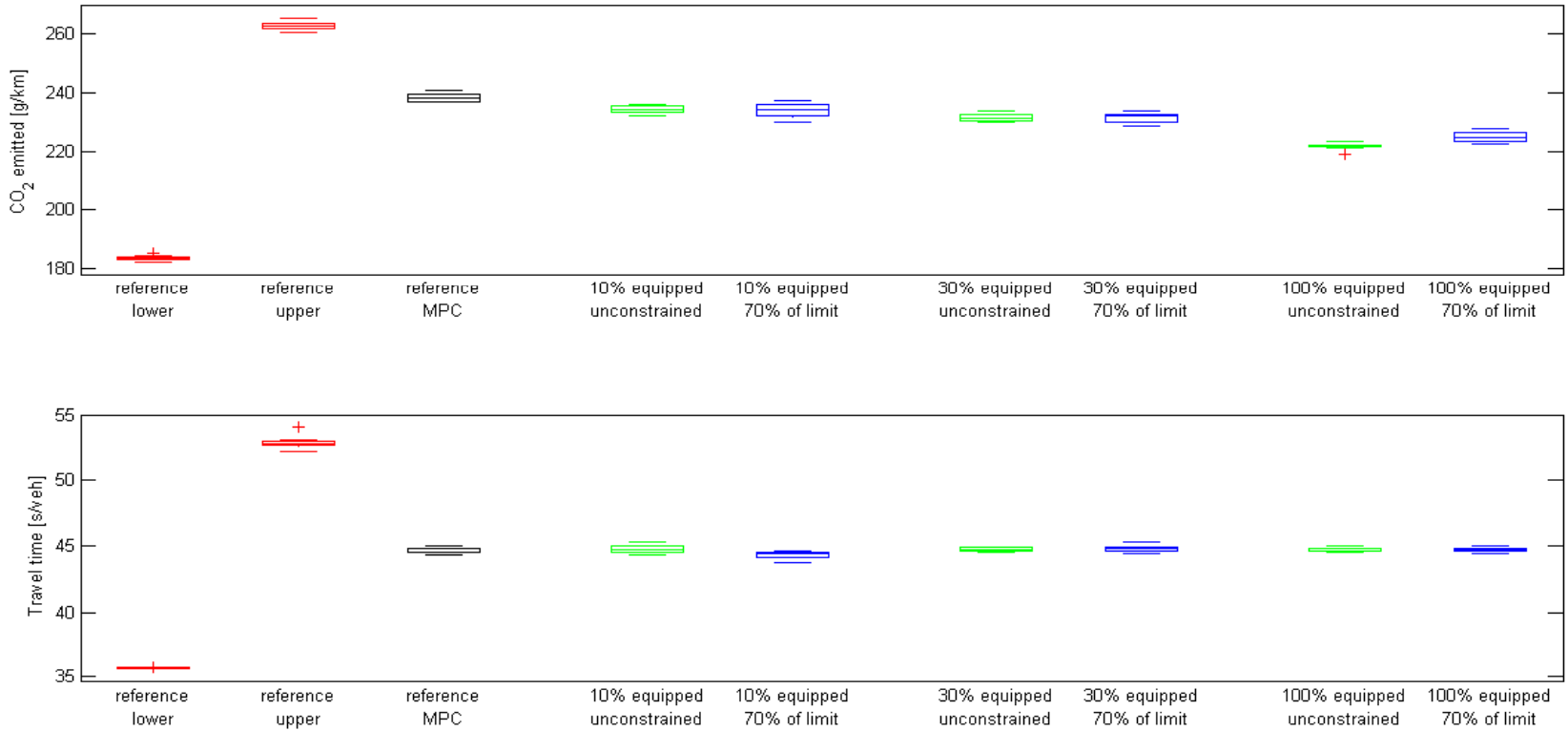


Controller	Objective	Improvements w.r.t. Traffic-Actuated control		Improvements w.r.t. Model Predictive Control	
		CO ₂ (g/veh)	Travel Time (s/veh)	CO ₂ (g/veh)	Travel Time (s/veh)
Conflictfree	delay	30,1%	32,6%	23,6%	21,6%
Actuated	delay	N/A	N/A	-9,2%	-16,5%
MPC	delay	8,5%	14,1%	N/A	N/A
MPC	++delay	9,3%	13,6%	0,9%	-0,6%
MPC	CO2	11,5%	6,7%	3,3%	-8,6%

Emission minimization: eCoApproach Advice

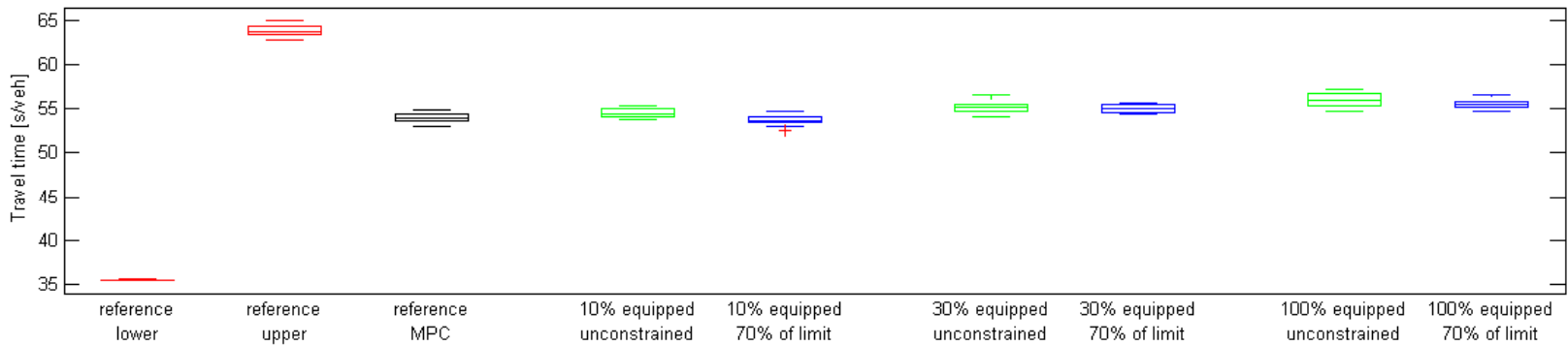
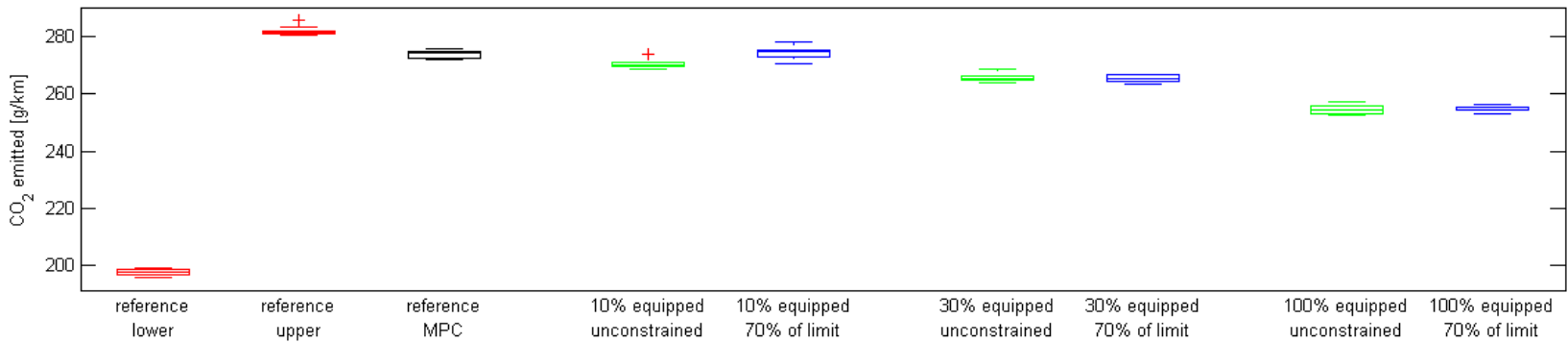


Off-peak hour results



Controller	Equipped	Advice	Improvements w.r.t. Traffic-Actuated control		Improvements w.r.t. Model Predictive Control	
			CO ₂ (g/veh)	Travel Time (s/veh)	CO ₂ (g/veh)	Travel Time (s/veh)
Conflictfree	0%	N/A	30,1%	32,6%	22,9%	20,3%
Actuated	0%	N/A	N/A	N/A	-10,2%	-18,3%
MPC	0%	N/A	9,3%	15,4%	N/A	N/A
MPC	10%	unconstrained	10,8%	15,3%	1,7%	-
MPC	10%	limited to 70%	10,9%	16,2%	1,8%	0,9%
MPC	30%	unconstrained	11,9%	15,4%	2,9%	-
MPC	30%	limited to 70%	11,9%	15,3%	2,9%	-
MPC	100%	unconstrained	15,6%	15,4%	7,0%	-
MPC	100%	limited to 70%	14,4%	15,5%	5,6%	-

Peak Hour results



Controller	Equipped	Advice	Improvements w.r.t. Traffic-Actuated Control		Improvements w.r.t. Model Predictive Control	
			CO ₂ (g/veh)	Travel Time (s/veh)	CO ₂ (g/veh)	Travel Time (s/veh)
Conflictfree	0%	N/A	29,9%	44,4%	27,9%	34,3%
Actuated	0%	N/A	N/A	N/A	-3,0%	-18,3%
MPC	0%	N/A	2,9%	15,5%	N/A	N/A
MPC	10%	unconstrained	4,1%	14,6%	1,2%	-1,0%
MPC	10%	limited to 70%	2,7%	16,0%	-	-
MPC	30%	unconstrained	5,7%	13,7%	2,9%	-2,2%
MPC	30%	limited to 70%	5,9%	13,9%	3,1%	-1,9%
MPC	100%	unconstrained	9,7%	12,3%	7,0%	-3,7%
MPC	100%	limited to 70%	9,6%	13,0%	6,9%	-2,9%

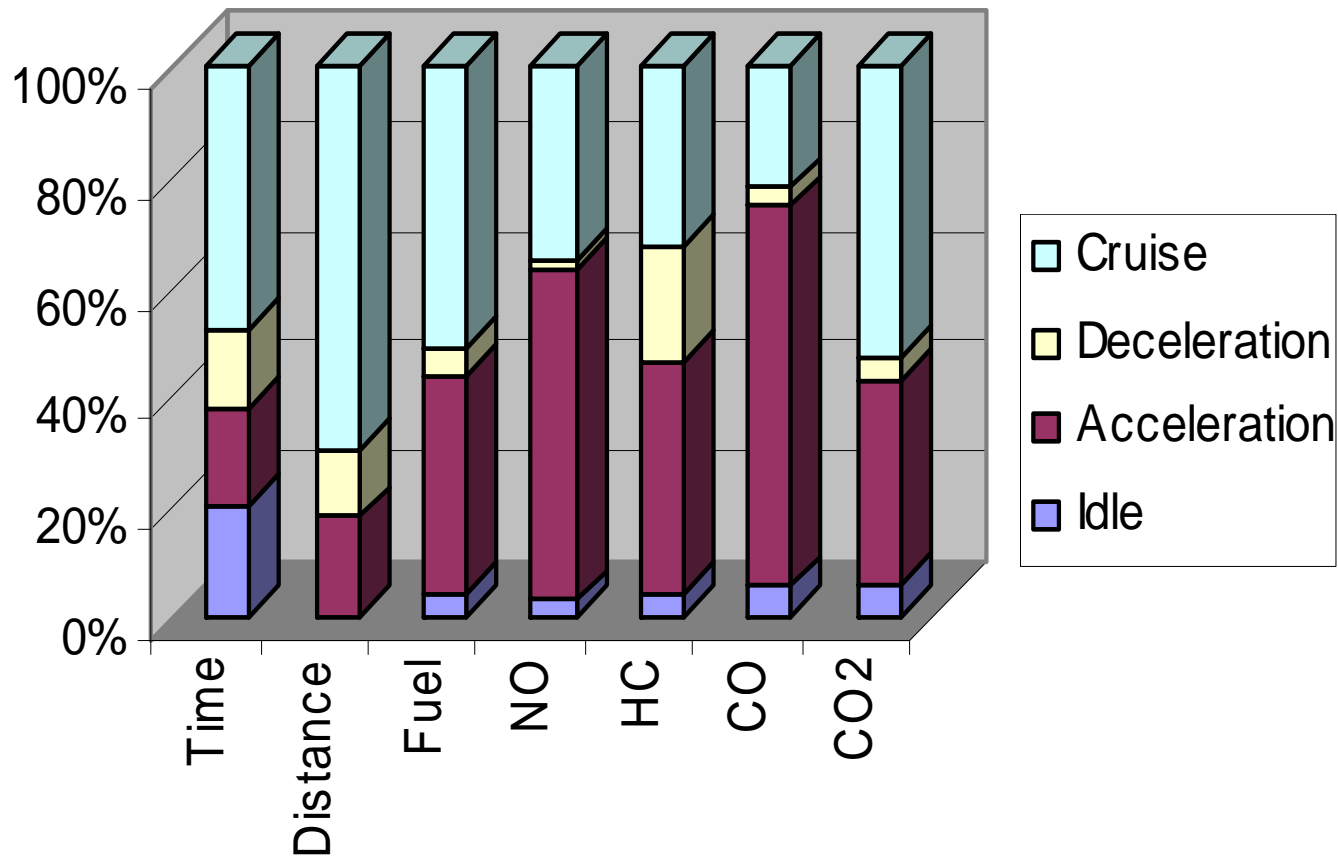
Contents

- Illustrating the concept for a single intersection
- **Concepts applied in a larger network**
 - Introduction to network concepts
 - Definition of the baseline
 - eCoBalanced Priority
 - eCoApproach Advice
 - eCoGreenwave
 - Combinations of applications

Strategy integration

- Assessment of interaction of different ITS solutions operating in the same domain
 - Complementarity: $A+B > A$ and $A+B > B$
 - Additivity: $(A+B) = A+B$
 - Synergy: $(A+B) > A + B$
 - Perfect substitutability: $A+B = A = B$
- Need for a state-based hierarchical coordination framework

Importance of Stops in network



Simulation network

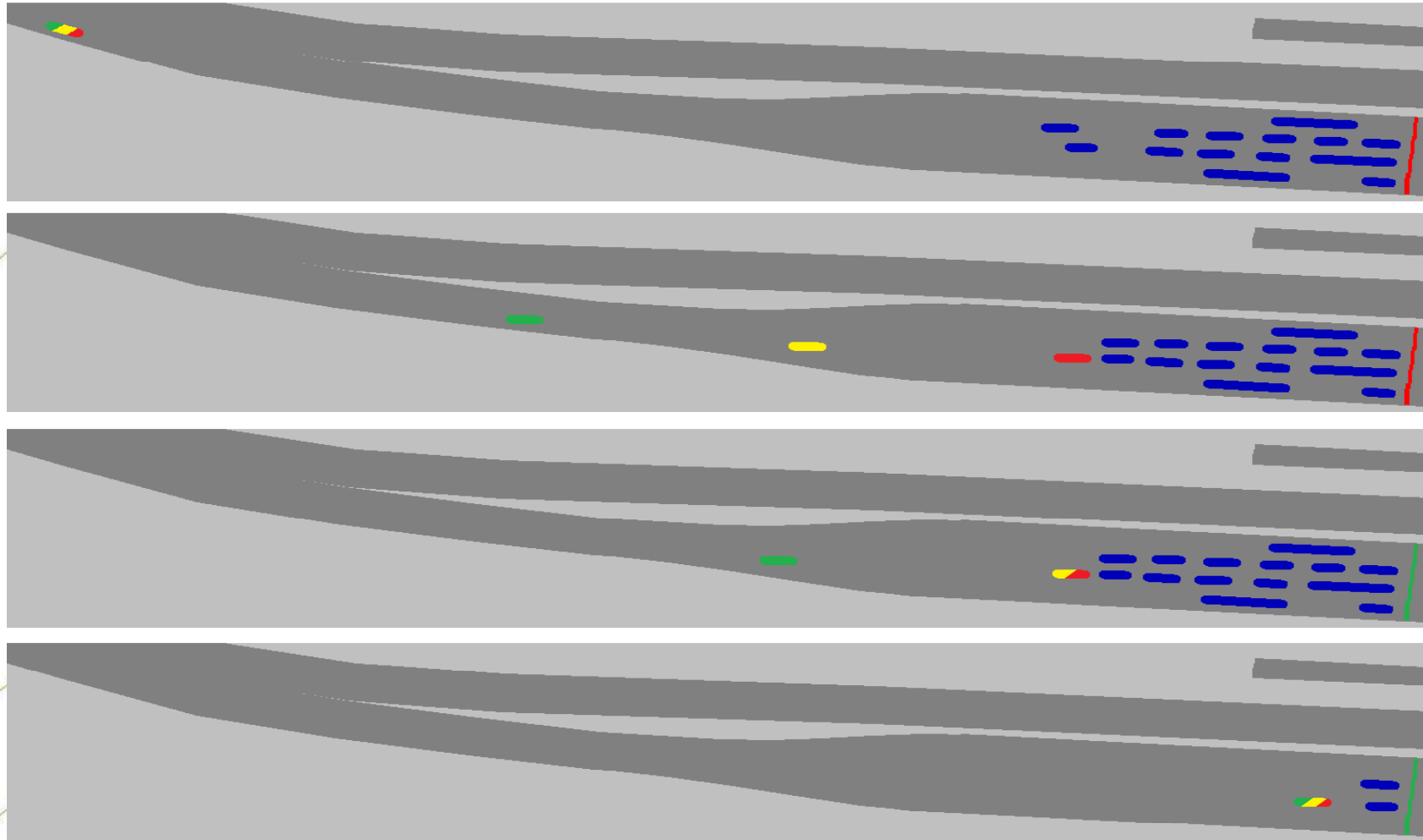
- Three adjacent intersections (<200m)
- Tradeoff ongoing traffic and local traffic



Baseline control

- Helmond currently has state-of-the-art Imflow control, comparable to MPC used on single intersection.
- Heavily optimized for ongoing traffic, but not for overall performance.
- Added actuated baseline to compare with more standard on-site situation.
- Slow traffic does not influence CO₂, but need acceptable waiting times nevertheless.

eCoApproachAdvice



eCoApproachAdvice

- Simulated driver behaviour problems
- Stable signal plan required
- Overtaking issues with low penetration
- Real-life pilot – CONTRAST (NL) -7% CO2

Measure	Total CO2	CO2 trucks	Number of Stops	Average Delay	Main direction	Other routes
Actuated	104.0%	105.9%	111.5%	101.6%	144.7%	62.5%
Adaptive Imflow	100%	100%	100%	100%	100%	100%
ecoApproach Advice	97.2%	89.6%	77.3%	92.4%	73.1%	99.4%

eCoBalanced Priority

- Green wave' for trucks [-13%]
 - Real-life pilot – e.g. FREILOT (EU)
 - Real-life validation – e.g. eCoMove (EU)
- Simulation
 - Priority only on main direction
 - Experiments with both balanced and “too much” priority
 - Up to 10.3% CO2 reduction

eCoBalanced Priority

Measure	Actuated	Adaptive Imflow	Priority 10%	Priority 100%	Priority + approach
Total CO2	104.0%	100%	99.0%	94.1%	98.9%
CO2 trucks	105.9%	100%	90.8%	89.7%	83.9%
Number of stops	111.5%	100%	100.1%	103.9%	89.4%
Average delay	101.6%	100%	109.9%	115.2%	109.9%
Main direction	144.7%	100%	106.4%	99.5%	86.5%
Other routes	62.5%	100%	95.9%	104.8%	111.7%

eCoGreenwave

- Few options for the algorithm to create green wave with small intersection spacing
- Baseline Imflow was better optimized for main direction!
- Off-peak delay increased 19.1%

Measure	Total CO2	CO2 trucks	Number of Stops	Average Delay	Main direction	Other routes
Actuated	104.0%	105.9%	111.5%	101.6%	144.7%	62.5%
Adaptive Imflow	100%	100%	100%	100%	100%	100%
eCoGreen Wave	100.1%	99.2%	96.0%	95.4%	107.1%	81.7%

eCoGreenwave + eCoApproachAdvice

- Solves problem of stable signal plan
- More opportunity for platoon shaping

Measure	Total CO2	CO2 trucks	Number of Stops	Average Delay	Main direction	Other routes
ecoApproach Advice	97.2%	89.6%	77.3%	92.4%	73.1%	99.4%
eCoGreen Wave	100.1%	99.2%	96.0%	95.4%	107.1%	81.7%
Combined	97.1%	89.5%	71.0%	78.0%	72.8%	82.4%

Thank you for your attention

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