Adaptive Traffic Signalling Strategies based on Deliberate and Connected Agents: A Reinforcement Learning Framework

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Outline

- Introduction
- Problem Description
- Current Approach
- Proposed Approach
- Test-bed in Step2Smart
- Indicative Results
- Future Steps

Introduction

- Step2Smart Project focus on the evaluation of the introduction of ‘Smart’ technologies in Nicosia’s (and by extrapolation Cyprus’) road network management.
- Among other traffic management approaches (mainly ATIS), the quantitative evaluation of ‘advanced’ traffic signalling strategies seemed vital.
- Indeed, a prefeasibility-type of investigation on the value of possible adoption of dynamic/adaptive/smart traffic signalling is conducted (and it is continued).
- During this investigation, alternative adaptive traffic signalling strategies are investigated, combining proactive and reactive learning approaches for optimizing signal plans.
- The results clearly indicate that SIGNIFICANT benefits can be anticipated in Nicosia if such strategies are employed.

Existing Situation

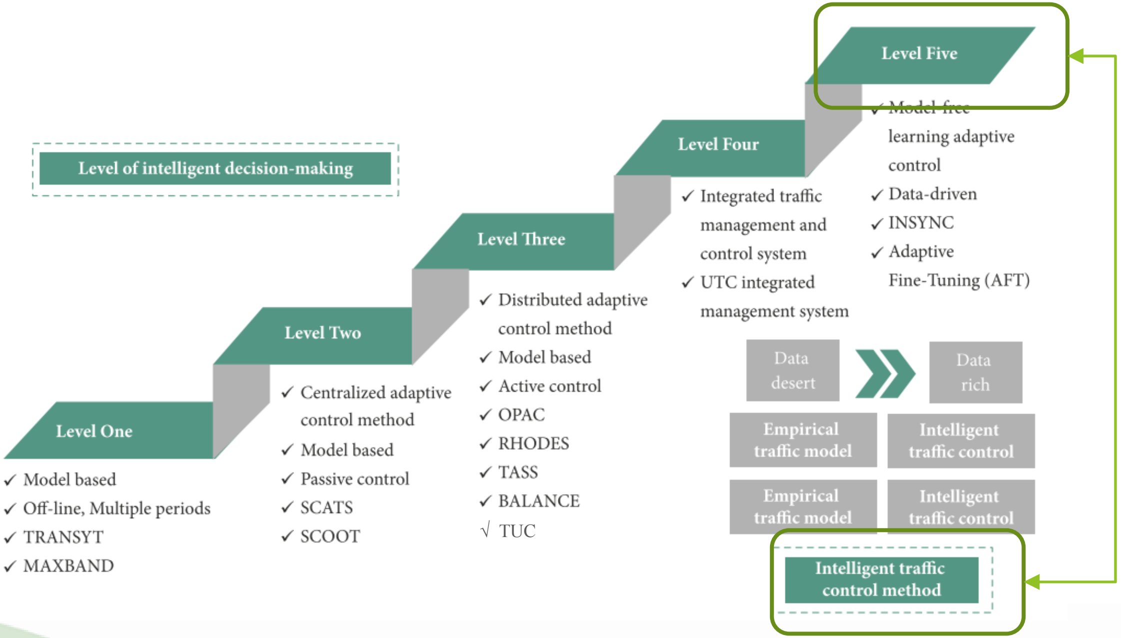
- Currently, Nicosia (and Cyprus') signalling strategy is based on pre-fixed time-based signal plans.
- All main corridors are 'heavily' signalized, with a mixture of actuated pedestrian crossings and traffic control intersections.
- The public perception on traffic conditions is that there are significant congested periods in Nicosia, while the traffic signals planning is obsolete, unreasonable and 'dump'.
- No synchronization/coordination exist, even in obvious urban corridors.

Step2Smart: an Opportunity for Change

- The MCTW and the Municipality of Nicosia are aware of this situation, but seem reluctant for drastic changes:
- No dedicated/experienced personnel is available,
- Massive investments have been allocated on ‘hard’ infrastructure,
- The investments on shifting to advanced traffic signalling mainly concerns the change of the signal head/lighting,

- **Step2Smart aimed on providing the Ministry with hard evidence on the benefits from the adoption of updated (if not advanced) dynamic signalling strategies.**

Evolution of traffic signal optimisation

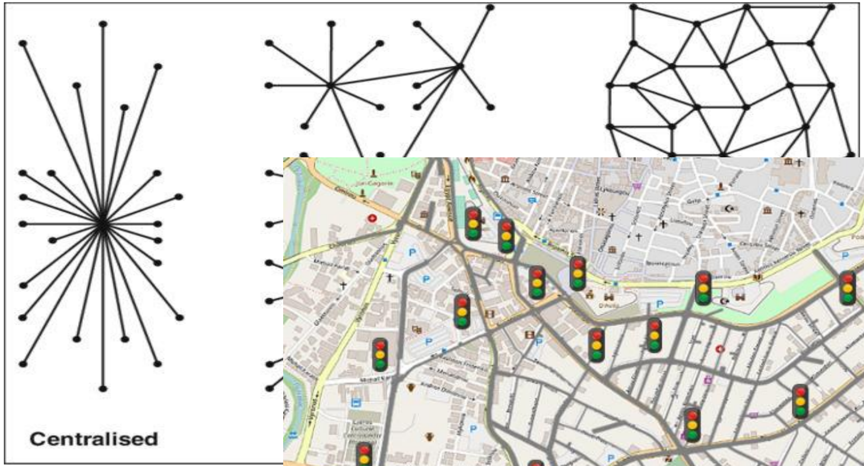


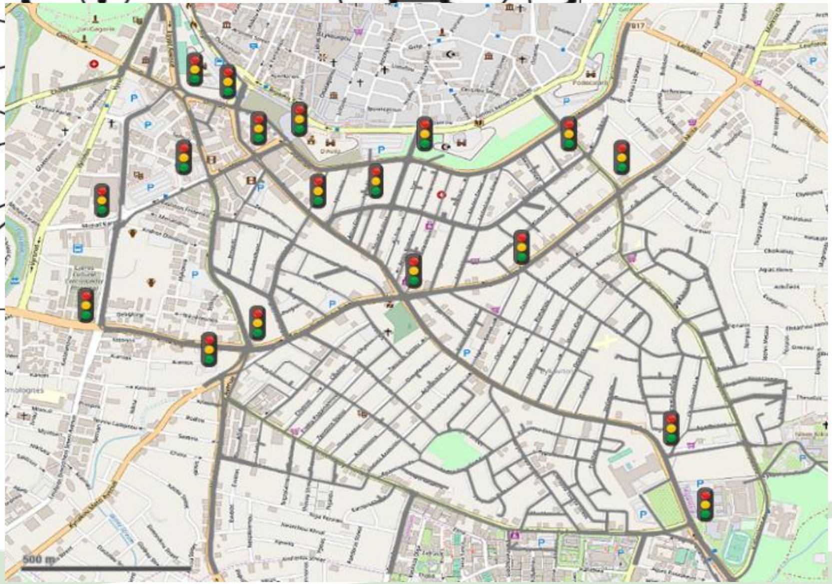
Sources: W. Yang, Study on Self-adaptive Coordinated Control Based on Close-loop Feedback for Urban Traffic Signals, Tongji university, Shanghai, 2015
Wang, Y., Yang, X., Liang, H., Liu, Y., 2018. A review of the self-adaptive traffic signal control system based on future traffic environment. J. Adv. Transp.
Gartner, N.H., Stamatiadis, C., Tarnoff, P.J., 1995. Development of advanced traffic signal control strategies for intelligent transportation systems: multilevel design. Transp. Res. Rec. 98-105.

Proposed Approach in Step2Smart

- In Step2Smart up to now we investigated a traffic signalling strategy that is:
  - model-free,
  - data-driven,
  - dynamic,
  - state-based, and
  - Agent-based
- We did so in because:
  - It is independent of specific traffic simulators
  - It is powerful for treating complex distributed control cases (like traffic signalling)
- The approach is based on **Reinforcement Learning Mechanics.**

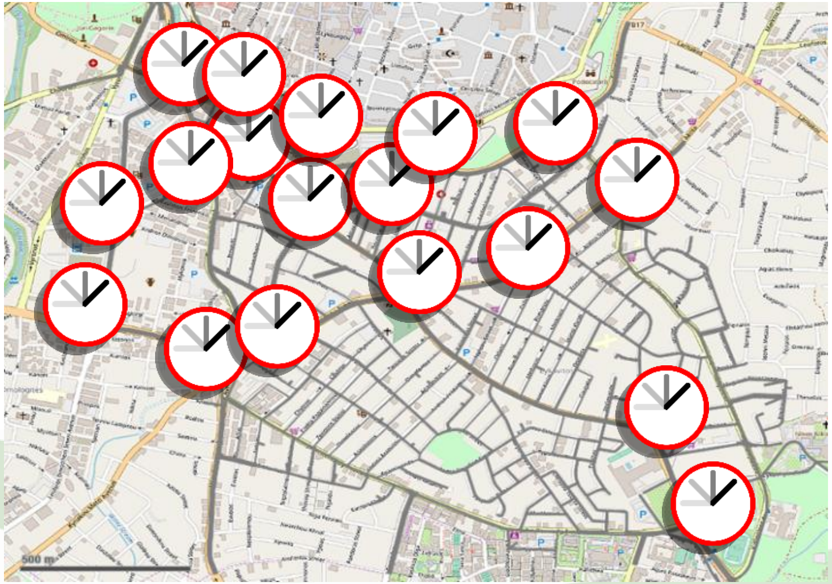
Control Approaches



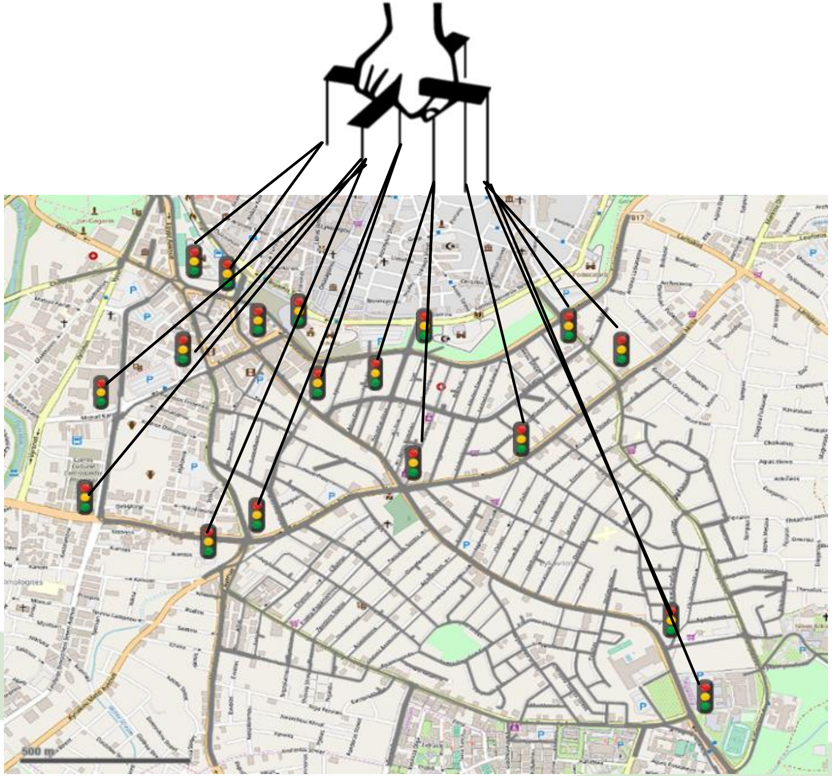


Decentralized pre-timed

- Currently the signal strategies applied in Cyprus is a pre-timed schedule of fixed times.

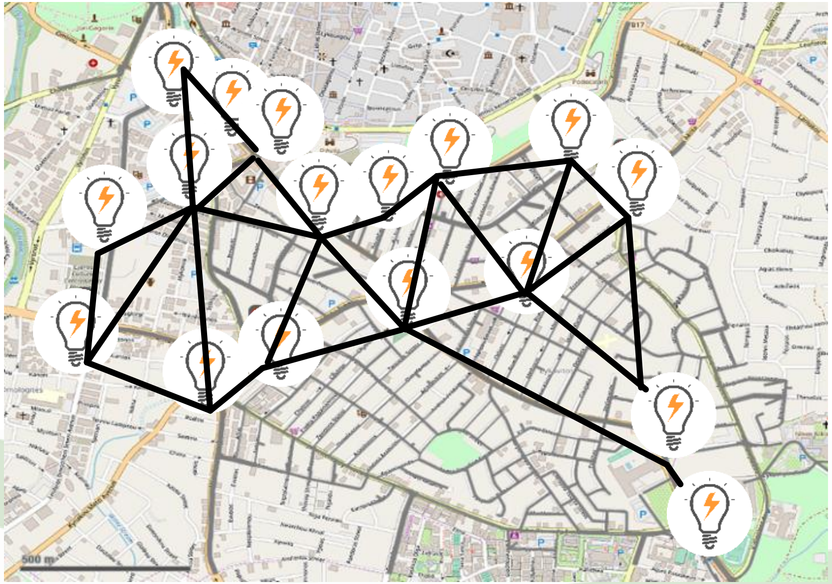


Centralized Control



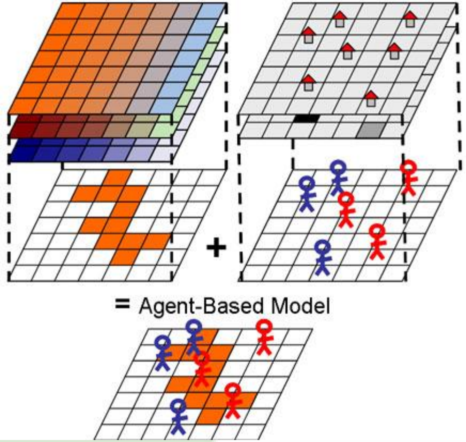
- Theoretically, centralized control may lead to optimum, if an accurate model of the system exist.
- But, more accurate models→ more information/complexity needed → no feasible solutions in real-time.
- Simpler traffic models → reduced execution time → but suboptimal solutions.

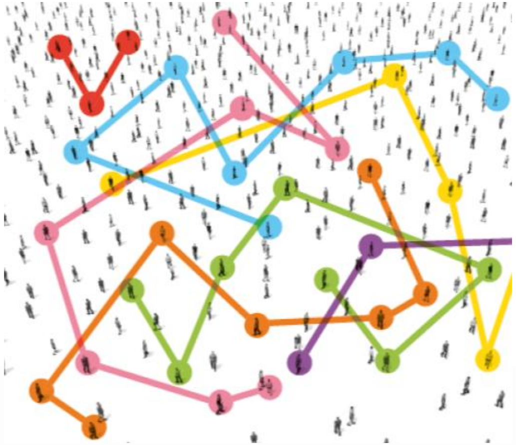
Distributed Control



- Theoretically, distributed control may lead to optimum, even in large-scale complex systems.
- But, the ‘summation’ of local optimality des not guaranty global optimum.
- In traffic systems that are connected by links (roads) the performance of each agent is depended on the performance of ‘neighbouring’ (effective) agents.
- Though, a careful implementation of ABM is necessary.

Reinforcement Learning (RL)

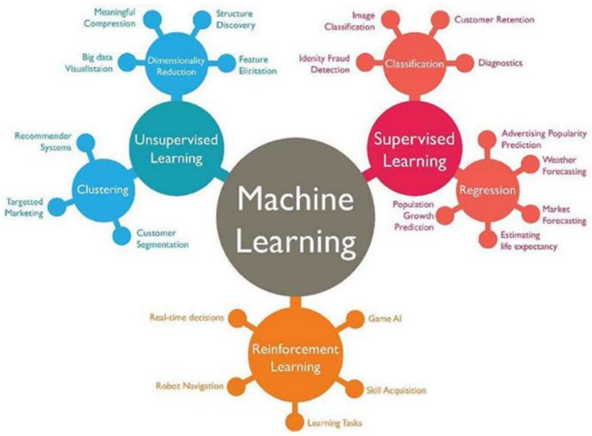


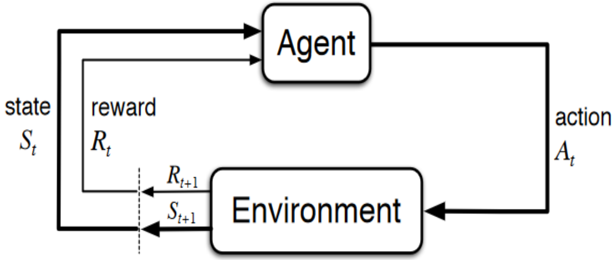


Reinforcement Learning (RL)

- Reinforcement Learning (RL) is a type of machine learning technique that enables an agent to learn in an interactive environment through trial and error. The agent learns using feedback from its own actions and experiences.

- Reinforcement learning is particularly well-suited to address highly dynamic problems that also include a long-term versus short-term reward trade-off.





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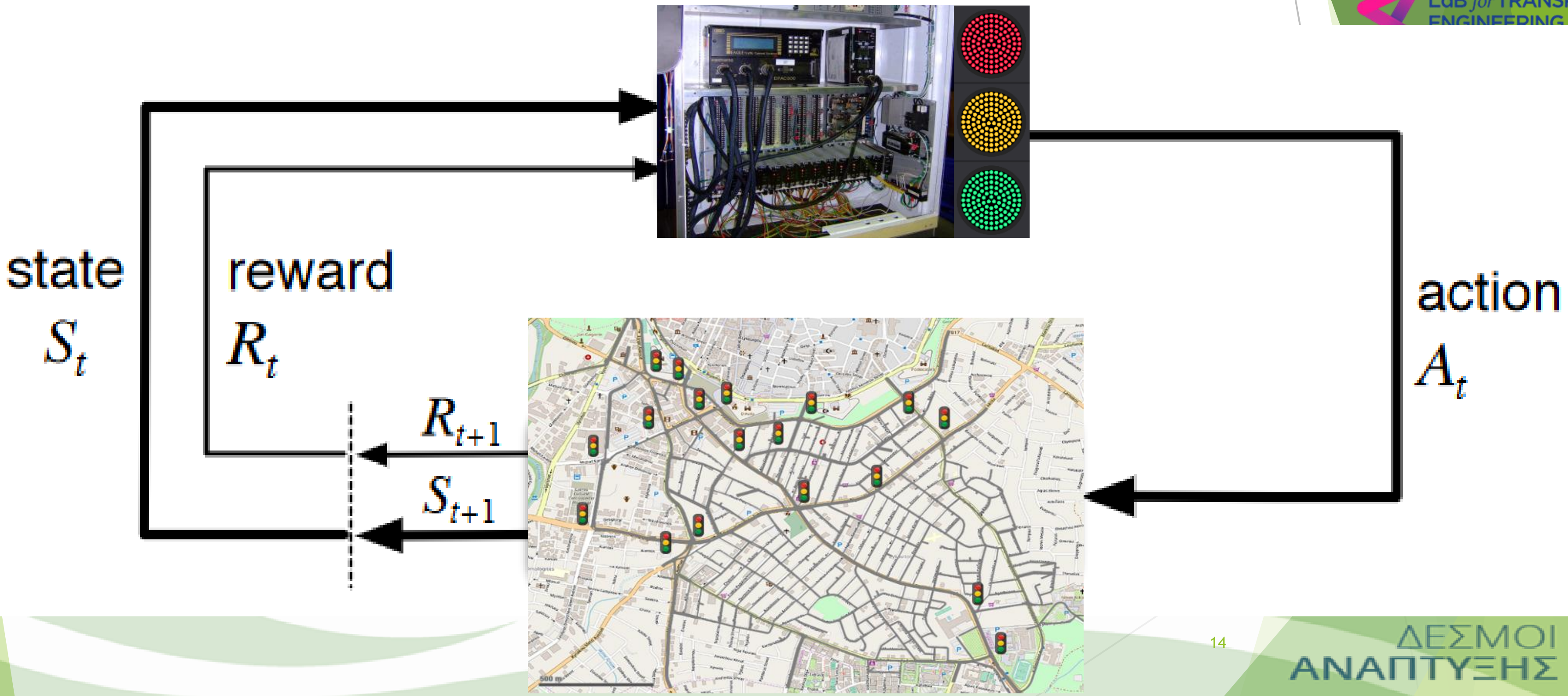


Q-Learning

- The agents’ decision making process has been approached through various methodologies.
- Q-Learning is a model-free implementation of RL where agents in state s_t choose the action a_t with the highest
Q-value
- Q-values are updated during the training of the model as:

$$Q(s_t,a_t) \leftarrow (1-\alpha)\cdot \underbrace{Q(s_t,a_t)}_{\text{old value}} + \underbrace{\alpha}_{\text{learning rate}} \cdot \overbrace{\left(\underbrace{r_t}_{\text{reward}} + \underbrace{\gamma}_{\text{discount factor}} \cdot \underbrace{\max_a Q(s_{t+1},a)}_{\text{estimate of optimal future value}} \right)}^{\text{learned value}}$$

Reinforcement Learning for traffic signal control

Environment

- The modelled road network

State

- Representation of traffic conditions (e.g. Queue lengths, Vehicle positions, active stages, etc.)

Agent

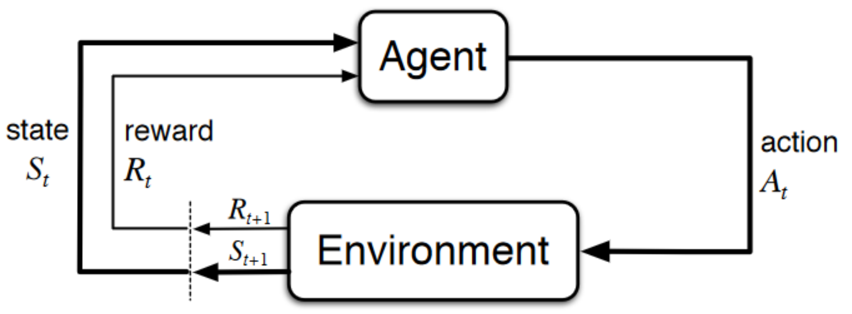
- Single signalised junction or groups

Action

- Choice of the active signal-phase

Reward

- Traffic conditions metric (e.g. Throughput, total length of queues, etc.)



RL model implementation

- Multiple agents with no coordination
- Q-learning
- The state is defined by the active traffic signal phase at each junction
- Signal phases take place cyclically and each agent decides at the beginning of each episode on retaining the active signal phase or progressing to the next
- Duration of episodes is 5 seconds
- Various reward mechanisms are evaluated (Throughput, Average queue length, Volume of CO emissions)
- Environment simulated by traffic microsimulation tool (Vissim) under Dynamic Traffic Assignment (DTA)

Case Study

- Nicosia faces significant congestion especially during the morning peak hour (07:00-08:00).
- Based on a calibrated traffic model for Nicosia, Cyprus (20 km^2)
- The network consists of 3,365 links and more than 200 junctions out of which 19 are signalised.
- The RL methodology is implemented and evaluated on all the signalised junctions.

Interreg
Ελλάδα–Κύπρος
Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης
step2smart

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ΔΕΣΜΟΙ ΑΝΑΠΤΥΞΗΣ

Case Study

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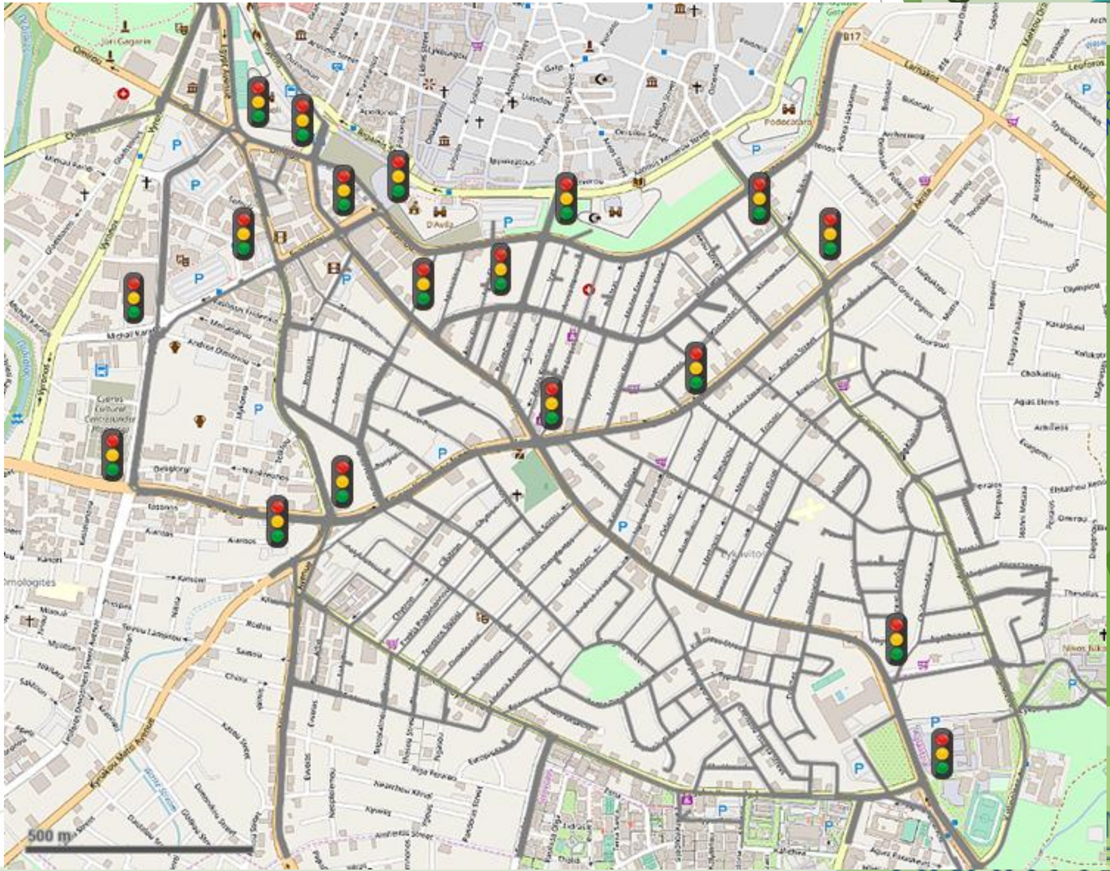
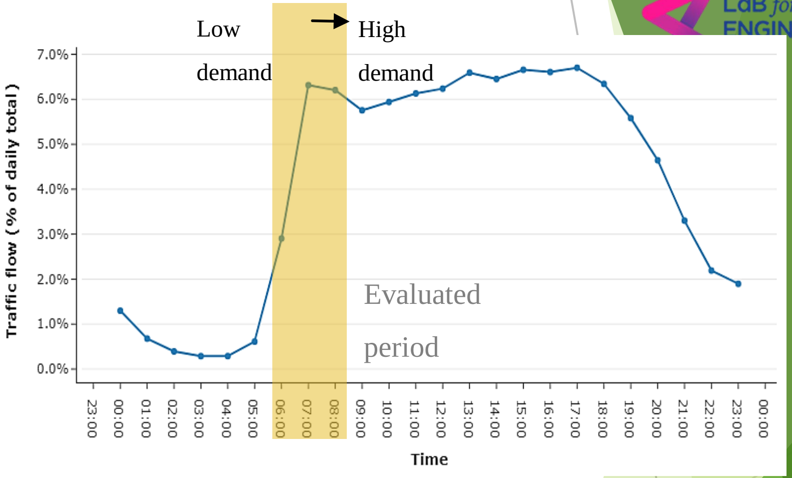


Case Study

- The simulations required for the completion of the experiments are conducted using the widely used traffic simulator VISSIM (Fellendorf and Vortisch, 2010).
- VISSIM is simulating driving behaviour based on a set of models allowing the estimation of the key driving elements (i.e. gap-acceptance, speed adaptation, lane-changing, overtakes, and car-following).
- In addition, VISSIM provides a Dynamic Traffic Assignment (DTA) module for the achievement of more realistic results in terms of route choice and traffic conditions.



Implementation Scenarios

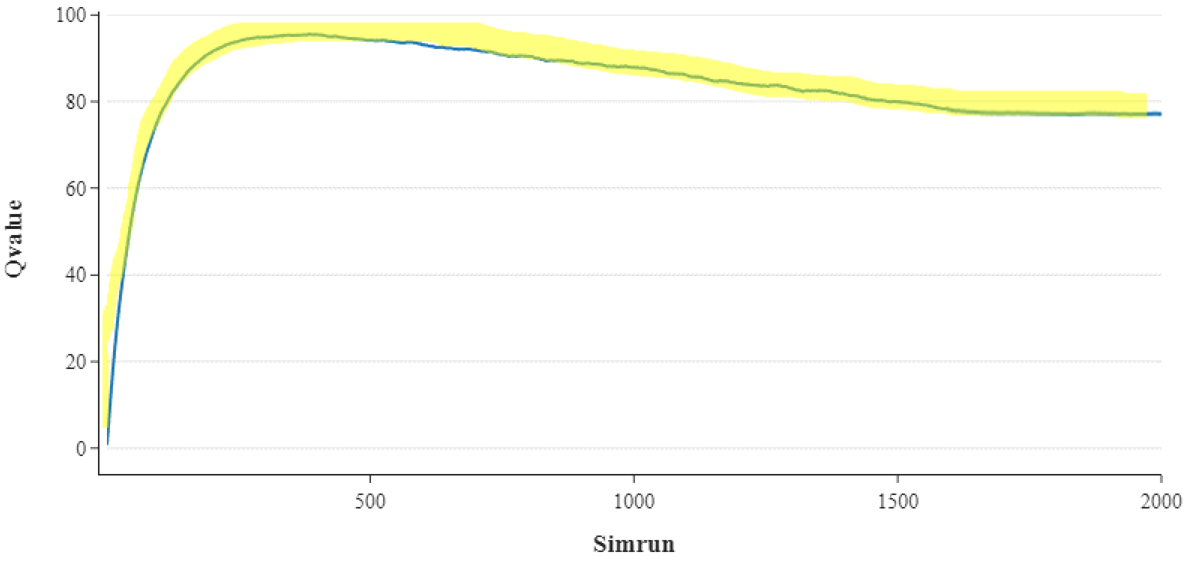
- Different implementation scenarios were developed based on three reward mechanisms
  A. Vehicles (i.e. throughput)
  B. Average queue length
  C. Volume of CO2 emissions

- All scenarios were executed for the AM peak hour (7:00 – 8:00) where over 16,000 trips take place

- Each modelled scenario was trained for 2,000 iterations
  (approximate processing time 12hrs)

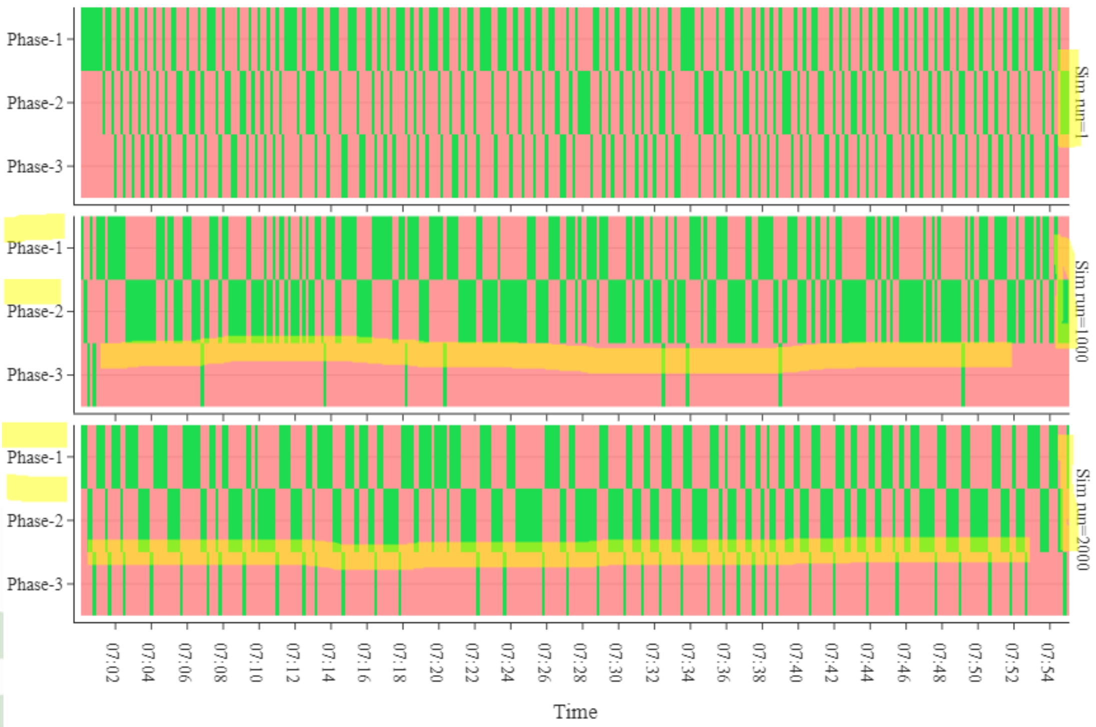
Model training

Average Q-value of all the executed actions



Model training

Evolution of signal programming

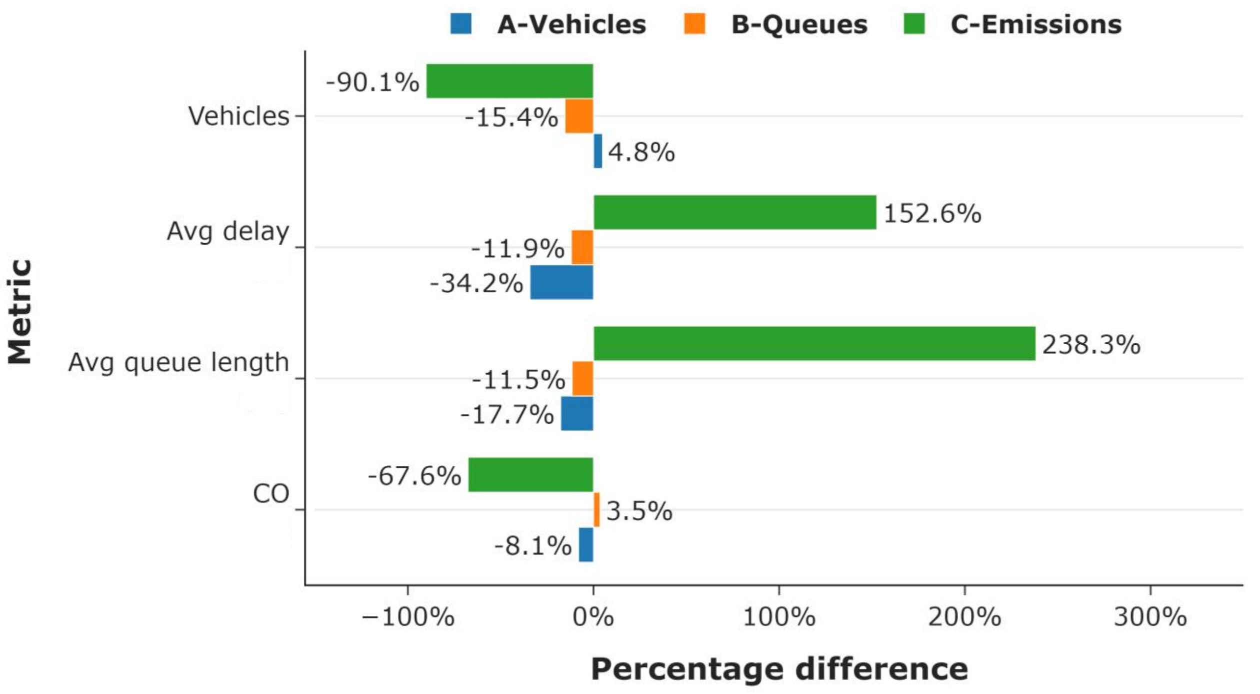


Evaluation metrics

- All the optimisation scenarios were evaluated in comparison to the existing fixed time signalling strategy
- The evaluation refers to the conditions around the optimised junctions in terms of:

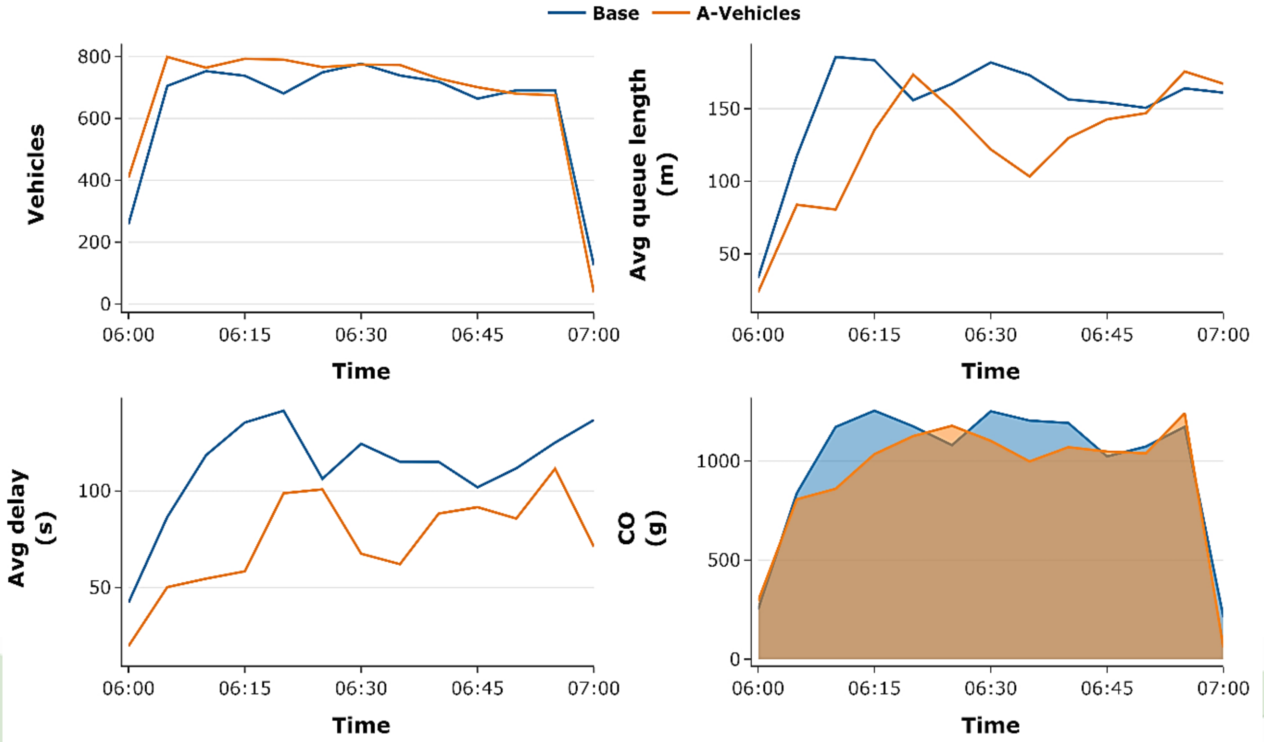
- Throughput
- Average delay
- Average queue length
- Total volume of CO emissions

Evaluation

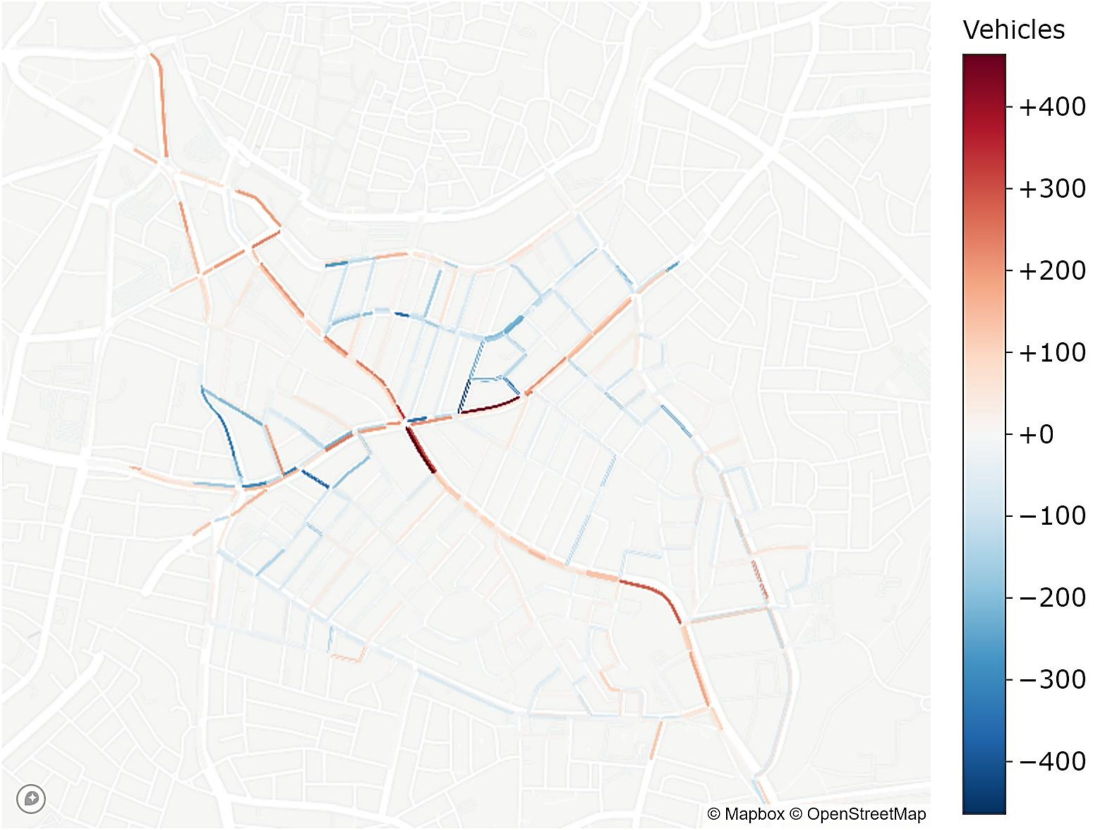


A-Vehicles
B-Queues
C-Emissions
Metric
Vehicles
Avg delay
Avg queue length
CO
-90.1%
-15.4%
4.8%
152.6%
-11.9%
-34.2%
238.3%
-11.5%
-17.7%
-67.6%
3.5%
-8.1%
−100%
0%
100%
200%
300%
Percentage difference

Dynamic Evaluation



Dynamic Evaluation



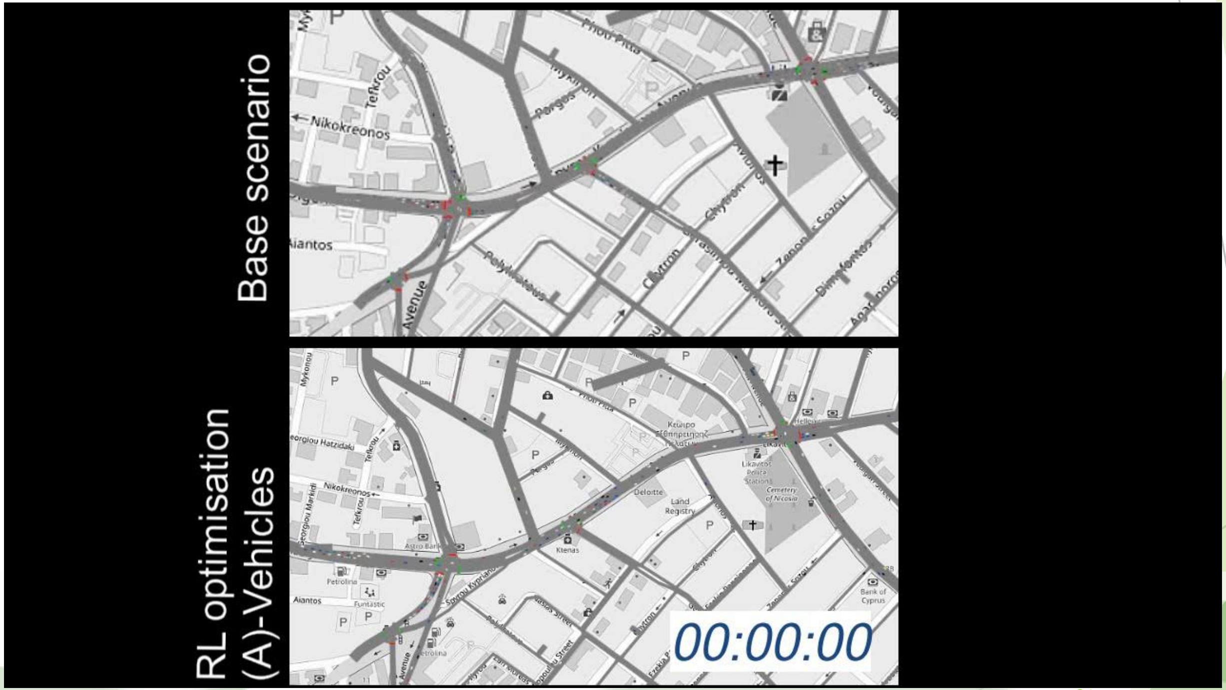
Snapshot comparison (Base scenario)

Snapshot comparison (RL-optimised)

- RL-based traffic management methodologies have a great potential to contribute towards a sustainable urban environment.
- Implementation details (e.g. reward mechanism) can strongly influence the performance of the outputted traffic signalling strategy.
- RL-based methodologies can be efficiently coupled with microsimulation tools to allow for large-scale evaluations.
- A common microsimulation framework for the evaluation of different RL-based methodologies under fully realistic conditions can prove very beneficial.

Conclusions

Simulation Comparisons



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Future Steps

- Although thorough investigations have been performed, documented and published (2 Conference papers and 2 Journal papers), significant findings (both methodological as well as technical) are to be presented.
- A field experiment on the application of adaptive signal control in the G. Diveni corridor is to be performed (February?) and detailed measured.

- **At the end we hope that we will have provided evidence, knowledge and experience to the Ministry and contribute to a decisive change of Nicosia (and Cyprus') signalling and traffic management. Thank You Step2Smart!**

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Thank you for your attention!

Questions/Suggestions?

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