Traffic Signal Control Simulation and Optimization

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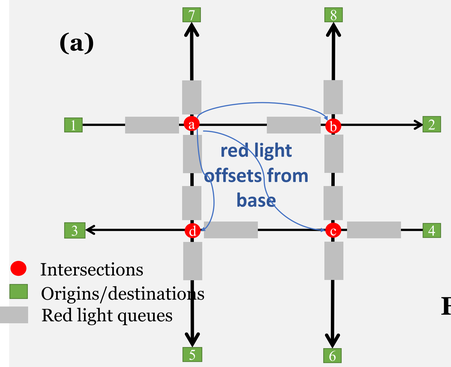
Traffic Signal Control Decisions: Problem Statement

Problem: $\min_{X} \mathbb{E}[F(X;\xi,\ell)]$

- F: **stochastic** objective value
- X: offset values from base (decision)
- ℓ: length of red and green lights
- ξ: **randomness** in the system



Motive: minimizing the cycle time per vehicle in a traffic system by choosing the offset value between red lights from a base is a hard problem with **many sources of randomness**.

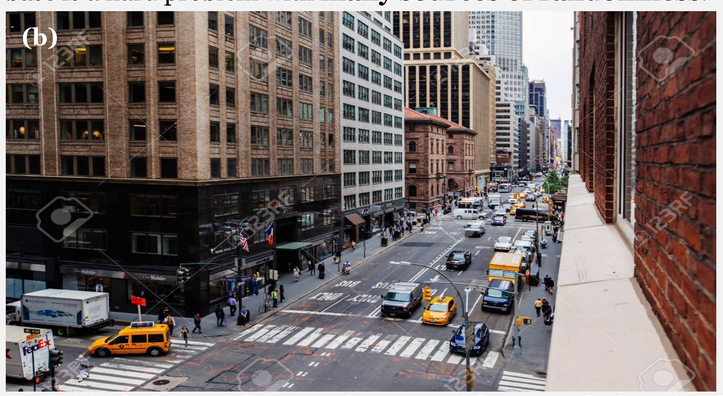


Fig 1. (a) shows a schema of a 2×2 grid network, inspired by Manhattan's grid-like structure, shown in (b).

Goal: developing a valid network-based simulation for the traffic signal control problem that can is extendable to higher dimensions and solvable in reasonable time to achieve reliable decisions.

Our Approach: Simulation Optimization

The challenge with simulation models is that every run of the model at the same decision returns different values due to randomness. Simulation Optimization, hence, solves the objective using **estimated values**.

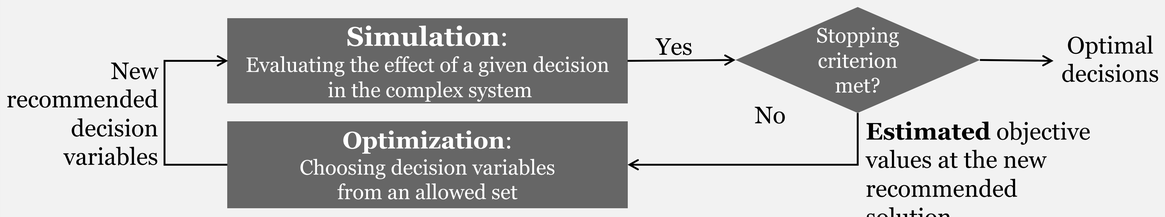


Fig 2. An iteration within a simulation optimization framework.

Classes of algorithms: model-based method, direct-search method, and gradient-based method.

Validation of the Simulation Model of Signal Control Problem

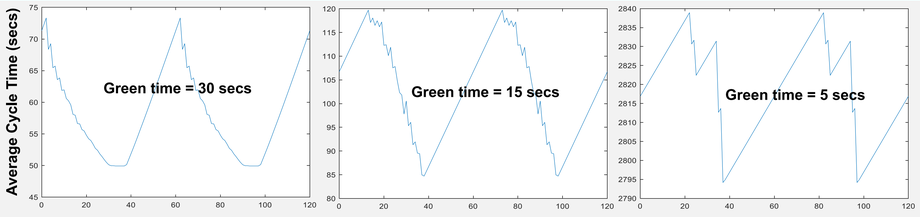


Fig 3. Sample-path function for two intersections and one offset. The x-axis is the offset value (decision) in seconds.

- We observe that the two-intersection problem is non-smooth and non-convex (i.e., hard to solve) and its sample-paths exhibit (i) periodic behavior and (ii) zig-zagging decline but sharp increase after min.
- These characteristics can be verified by analyzing the dynamics of the system.

Expansion of Traffic Signal Control Problem

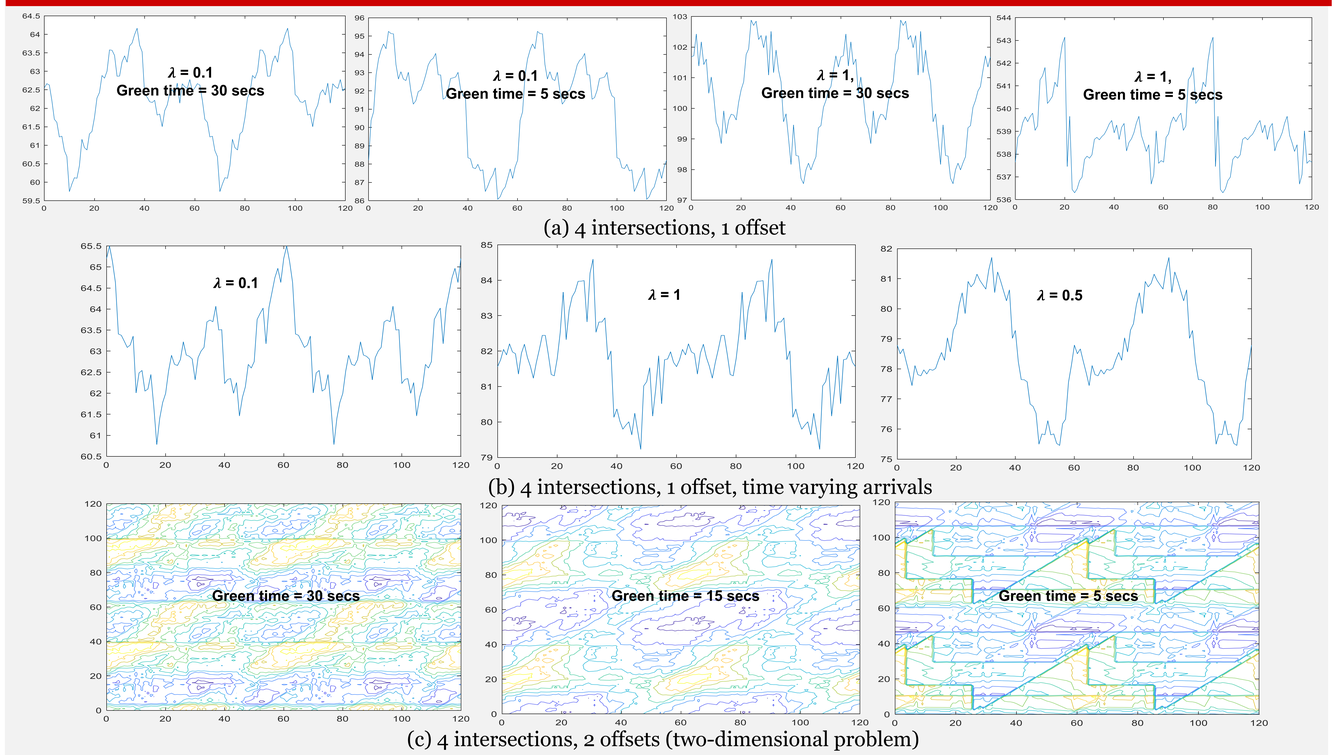


Fig 4. Sample-path function for a variety parameters that include the arrival, probabilities of choosing destinations, and the length of lights.
(x-axis: offset values, y-axis: average cycle time in seconds, λ: the arrival rates)

Result & Conclusion

The complex Traffic Signal System can be mimicked by the simulation model. We made the simulation model for various traffic signal control problems. In general, the model-based methods show good performance.

Optimization Method:

1. Model-based method
   - ASTRO-DF
   - STRONG
2. Direct-search method
   - NELDMD
3. Gradient-based method
   - SPSA

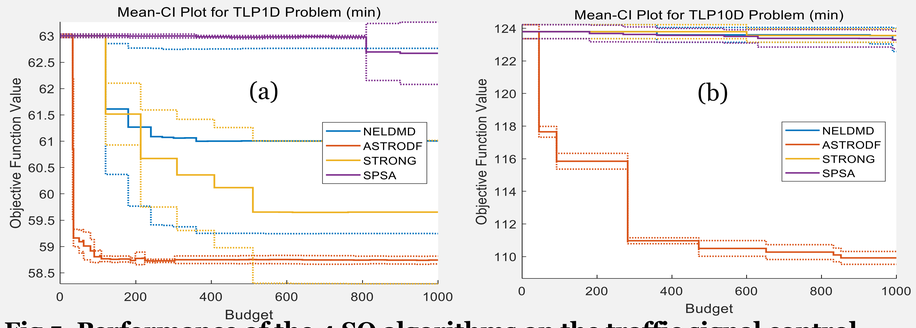


Fig 5. Performance of the 4 SO algorithms on the traffic signal control problems: (a) 2 intersections, 1 offset case. (b) 10 intersections, 9 offsets case.

References
- Osorio, C., and L. Chong. 2012. "An efficient simulation-based optimization algorithm for large-scale transportation problems". *In Proceedings of the 2012 Winter Simulation Conference.*
- Shashaani, S., F. Hashemi, and R. Pasupathy. 2018. "ASTRO-DF: A class of adaptive sampling trust-region algorithms for derivative-free stochastic optimization". *SIAM Journal on Optimization28(4):3145–3176.*