A CASP-based Solution for Traffic Signal Optimisation - Extended Abstract

Alice Tarzariol[1], Marco Maratea[2], and Mauro Vallati[3]

[1] AICS, University of Klagenfurt, Austria
[2] DeMaCS, University of Calabria, Italy
[3] School of Computing and Engineering, University of Huddersfield, UK

1 Introduction and Problem Description

This extended abstract refers to a paper presented at ICLP 2025 and published in Theory and Practice of Logic Programming (TPLP) [11]. In the paper, we investigate the application of Constraint Answer Set Programming (CASP) [7, 1, 6, 4] in the context of urban traffic control. Specifically, we focus on the *Traffic Signal Optimization Problem*, which aims to minimize the average traffic delay for a region of interest by determining the optimal green length for each traffic signal in a given set.

The application scenario and problem abstraction used in this paper is based on a work that applied the mixed discrete-continuous variant of the Planning Domain Definition Language (PDDL+) [3] on a major corridor in the Kirklees council area within West Yorkshire (UK), containing 6 junctions and 34 road links [5]. The problem is framed using a mesoscopic traffic model, where the approximate number of vehicles in road links is considered (instead of individual vehicles) and the traffic signals in a junction are abstracted as *stages*, each representing a set of simultaneous traffic movements. A *cycle* is the ordered sequence of these stages, separated by *intergreen* times. Constraints apply to the minimum and maximum durations of both stages and full cycles, while the order of stages remains fixed. The SCOOT system [10], a traffic reactive control mechanism, is in operation in the focus area for handling cycle-to-cycle changes in traffic demand. It stores in a dedicated database data obtained from local sensors and operational information, which can be exploited to simulate historical data and generated solutions. This allows for the use of external tools, e.g., ASP and PDDL+ solvers, to perform traffic signal optimization by injecting generated strategies to be deployed in the region. However, to operate on legacy infrastructure, additional constraints must be respected, i.e., for each junction, the length of the stages is defined according to a set of possible predefined *cycle configurations*, and junction cycles must remain of similar duration to preserve synchronization and green waves. To minimise the average traffic delay, the problem formalisation uses the concept of *counter*, introduced by Percassi et al.[8], to measure the number of vehicles that navigated through the link over a considered period of time. Maximizing these counters serves as a proxy for reducing delays, since higher counters imply less queuing.

2 Proposed Approach and Experimental Results

Despite the successful deployments, PDDL+ has limitations when it comes to specifying optimisation statements and to computing optimal plans, which are particularly useful in practice to ensure that benefits materialise in the controlled region as soon as possible. Indeed, at the state of the art, PDDL+ planning engines focus on generating satisfying solutions, with no guarantees on the quality of the solution found. In practice, this can lead to traffic signal optimisation plans that show extremely long time horizons – potentially reducing the ability of plans to cope with identified issues. Considering the characteristics of the setting used in the work of Kouaiti et al. [5], we investigated the potential of applying ASP and seeing whether it is possible to overcome PDDL+ limitations.

In the simulation, we discretised the time in seconds and considered a horizon of up 900 seconds (i.e., 15 minutes), which is the maximum duration for which the SCOOT data remains representative. The ASP solver decisions only concern which configuration is selected for each junction. Since (*i*) the duration of each cycle is the same (regardless of the configuration), and (*ii*) once a configuration is selected, it cannot be changed unless the cycle ends, the decision points can be precomputed, drastically reducing their number. Despite this observation, calculating the occupancy and counter for the 34 road links at each second produced a number of ground rules that cannot be handled, even for short horizons (around 100 seconds). To overcome this issue, we applied the system *clingcon* [2], which extends the well-known ASP solver *clingo* with theory atoms and propagators for linear constraints. By redefining through theory atoms the road link occupancies and counters, we managed to model and effectively apply a CASP-approach to tackle the traffic signal optimization problem with meaningful horizons, i.e., up to 900 seconds. The instances, ASP and *clingcon* encoding, as well as the experiment setup can be found at this link https://github.com/altarzariol/traf_sign_casp, while more details on the experiments can be found in our journal paper [11]. We compared the performance of our encoding run with *clingcon* and the best PDDL+ model proposed by Kouaiti et al. [5] with the planner *enhsp* [9], showing that our approach is a valuable alternative for the considered task. In particular, we observed that CASP and PDDL+ can be combined to exploit the benefits provided by both approaches, where the former can be used to improve the quality of solutions returned by the latter approach. We implemented an automated pipeline to exploit the synergies of the two approaches as follows: from the solution found by the PDDL+ planner, the values of *counter* at a given horizon of each target link can be extracted. This information can be encoded as ASP atoms that appear in constraints forcing *clingcon* to return a solution that is strictly better than the PDDL+ one. In this way, thanks to PDDL+, we have the guarantee to have a solution quickly, while the subsequent application of *clingcon* allows for trying to improve it (which was observed for almost half of the benchmark instances).

Lastly, we also analysed how *clingcon* can further exploit its optimisation capabilities to express alternative optimisation goals, making the suggested model modular and capable of adapting to different targets.

Acknowledgments Mauro Vallati was supported by a UKRI Future Leaders Fellowship [grant number MR/Z00005X/1]. Marco Maratea was supported by the European Union - NextGenerationEU and by Italian Ministry of Research (MUR) under PNRR project FAIR "Future AI Research", CUP H23C22000860006. This research was funded in part by the Austrian Science Fund (FWF) 10.55776/COE12.

References

[1] Marcello Balduccini and Yuliya Lierler. "Constraint answer set solver EZCSP and why integration schemas matter". In: *Theory Pract. Log. Program.* 17.4 (2017), pp. 462–515.

[2] Mutsunori Banbara et al. "Clingcon: The next generation". In: *Theory and Practice of Logic Programming* 17.4 (2017), pp. 408–461. DOI: 10.1017/S1471068417000138.

[3] Maria Fox and Derek Long. "Modelling Mixed Discrete-Continuous Domains for Planning". In: *J. Artif. Intell. Res.* 27 (2006), pp. 235–297.

[4] Tomi Janhunen et al. "Clingo goes linear constraints over reals and integers". In: *Theory Pract. Log. Program.* 17 (2017), pp. 872–888.

[5] Anas El Kouaiti et al. "PDDL+ Models for Deployable yet Effective Traffic Signal Optimisation". In: *Proceedings of ICAPS*. 2024, pp. 168–177.

[6] Guohua Liu, Tomi Janhunen, and Ilkka Niemelä. "Answer Set Programming via Mixed Integer Programming". In: *Principles of Knowledge Representation and Reasoning: Proceedings of the Thirteenth International Conference, KR*. AAAI Press, 2012.

[7] Veena S. Mellarkod, Michael Gelfond, and Yuanlin Zhang. "Integrating answer set programming and constraint logic programming". In: *Ann. Math. Artif. Intell.* 53.1-4 (2008), pp. 251–287.

[8] Francesco Percassi et al. "An Efficient Heuristic for AI-based Urban Traffic Control". In: *Proc. of MT-ITS*. IEEE, 2023, pp. 1–6.

[9] Enrico Scala et al. "Subgoaling Techniques for Satisficing and Optimal NumericPlanning". In: *J. Artif. Intell. Res.* 68 (2020), pp. 691–752.

[10] Henk Taale, Walter Fransen, and John Dibbits. "The second assessment of the SCOOT system in Nijmegen". In: *IEEE Road Transport Information and Control*. 21-23. Apr. 1998.

[11] Alice Tarzariol, Marco Maratea, and Mauro Vallati. "A CASP-based Solution for Traffic Signal Optimisation". In: *Theory and Practice of Logic Programming* (2025), pp. 1–19. DOI: 10.1017/S1471068425100306.