AI Planning for Integrated Urban Traffic Control
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Executive summary

The problem of tackling traffic congestion in an urban region is challenging and multifaceted, due to the complex interplay between data interpretation and available controlling actions, and requires a holistic view to be effectively dealt with. Traditionally, urban traffic control is performed by using reactive approaches capable of controlling traffic lights. New modes of transport, such as Connected and Autonomous Vehicles (CAVs) are disrupting the transportation sector, and hold the promise of significant benefits in terms of better traffic control.

Simplifai Systems has successfully applied AI Planning to the management of traffic lights in urban areas, and is now looking to expand the scope of the existing AI Planning-based methods to include the management of CAVs as the management of planned or unplanned incidents in urban areas. This expansion presents a unique opportunity to apply AI Planning to a complex and multifaceted problem, involving contingent aspects and complex interactions between the infrastructure and the vehicles, with the potential of significant impact on the society and on the economy.

1 Context

Over half of the world's population now lives in cities and global urbanisation continues at a steady pace. As this trend continues, mobility is becoming an increasingly critical problem. In the UK alone, the cost of congestion has reached nearly £8 billion in 2018 in lost time and fuel consumption, and has become a major health threat that goes beyond the cardiac and respiratory systems.

Current urban traffic control techniques are restricted to operational tools such as traffic lights management and variable message signs. Existing approaches for traffic lights management that can deal in real-time with traffic congestion are mostly reactive. Approaches such as SCOOT or SCATS, which are widely exploited, are based on simple models of traffic within a small cluster of connected traffic lights. They can react to traffic congestion, but they rely on pre-computed knowledge and very simplified traffic models; therefore, the generated strategies tend not to be so effective. They are bound to react to certain pre-defined conditions in order to optimise a fixed metric, and are not able to adapt to different conditions or requirements. This approach is problematic when unusual or unexpected events happen: considering the impact of COVID-19, for instance, traffic volumes have suddenly varied from −80% to +30% of typical pre-COVID traffic conditions, and the composition and journeys of traffic have drastically changed as well. On a different scale, frequent issues such as car accidents, or major disruptions due for instance to emergency unplanned roadworks or environmental disasters, can lead to situations where traditional approaches for urban traffic control are ineffective or even detrimental. AI Planning can be used to generate strategies for dealing with unusual circumstances in real time.
On this regard, Simplifai Systems has successfully applied AI Planning to the management of traffic lights in urban areas, resulting in a patent application (https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2020148282 in United Kingdom GB2110405.4, China CN113924585, and United States US17422996) and in a number of academic publications.

The advent of Connected Autonomous Vehicles (CAVs) presents a unique opportunity for a fundamental change in urban traffic control. CAVs hold the promise of significant benefits in terms of, for instance, accident prevention, decreased carbon emissions, time savings, and better traffic control. Vehicle to infrastructure communication (V2I) capabilities of CAVs can provide a new range of tools for urban traffic controllers to affect traffic conditions: CAVs can provide information about traffic conditions, and can receive information about the best route to be followed to reach their destination. In this context, Simplifai Systems is looking to extend the capabilities of the patented AI Planning approach, by including the management of CAVs as part of the management of planned and unplanned incidents in urban areas. The AI planning-based management combining traffic lights and CAVs route can allow to exploit the synergies between the two intervention tools, and support a more encompassing control of traffic in urban regions.

2 Planning Application

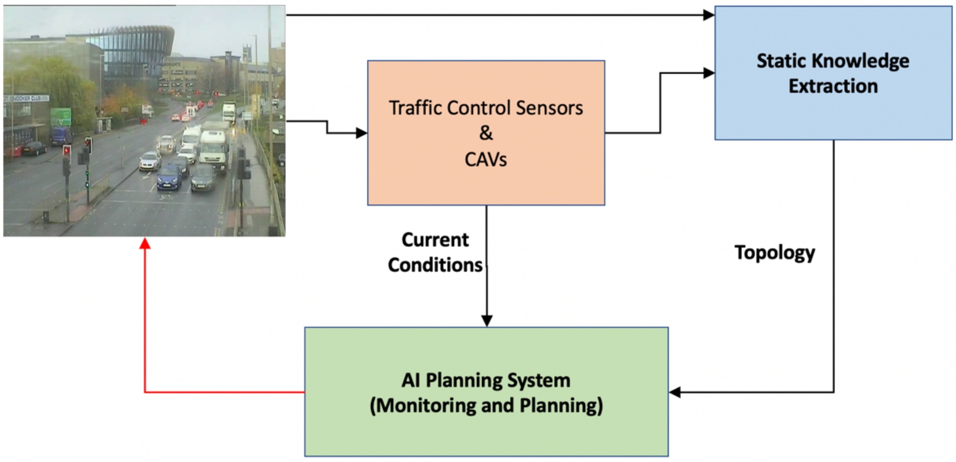

Figure 1. An overview of the proposed architecture for using AI Planning in Urban Traffic Control Extended with CAVs

In the considered Urban Traffic Control scenario, as described in Section 1, AI planning is used in response to unexpected traffic conditions, as depicted in Figure 1. The idea is that a planning system is in charge of controlling a urban network, and has the possibility to communicate with traffic lights and CAVs in the region. The overall architecture is currently based on the principle of exploiting as much as possible the existing traffic control infrastructure. For instance, one or more junctions in a urban region can be controlled by a SCOOT system: such system will have its own sensors in place, and a way to understand traffic conditions according to the readings of existing sensors. Further, real-time communication with CAVs navigating the region or approaching the controlled region can be established, to integrate the information provided by the sensors' infrastructure.

When some unexpected or undesired conditions are observed, a snapshot of the current status of the network is provided as input of the planning system that, also taking into account some "static" knowledge about the topology of the network and the actions that can be put in place to control traffic (e.g., maximum length of green stages, sequence of stages in a junction, on-demand stages, re-routing CAVs, etc.), is expected to generate a strategy plan that mitigates as quickly as possible the issue. In the considered CAVs-extended traffic control, a strategy plan is a detailed sequence of traffic light stages with a corresponding associated time, coupled with detailed instructions for CAVs already in the region or approaching the region. In other words, the planning system is expected to generate: (i) for each controlled junction, a strategy that describes the sequence of greens, and their length, and (ii) for each CAV currently in the network or approaching it, detailed instructions about the best route to take, or whether to avoid the region if possible. Notably, the integration of traffic light strategies and CAVs routing has not been explored before, and can provide extensive benefits: for instance, CAVs can be routed away from a critically congested corridor in an efficient way by generating appropriate green waves.

The quality of the generated traffic light strategies can be assessed according to the time that it requires to improve traffic conditions in the controlled region. The faster traffic returns to normal levels, the better the quality of the strategy is. This can be measured in simulation, by relying on historical data and by comparing against default strategies. Traffic conditions are usually measured in terms of journey times, i.e. the time needed to navigate between two points of a controlled region.

There are of course contingent aspects to take into account when exploiting AI planning for controlling urban traffic: (i) between junctions there is usually the presence of pedestrian crossings that can interrupt the flow of vehicles on the corresponding roads, (ii) weather conditions can have a significant impact on the way in which vehicles move in the region and on the number of vehicles, and (iii) there is the possibility of malfunctioning CAVS, or of CAVs that are not following the provided instructions. The mentioned contingent aspects have to be taken into account by the planning system.

In the considered architecture, the planning system can be invoked many times per day, according to the conditions of traffic, and according to non-predictable issues that can happen. Traffic accidents, roadworks, public events, are all examples of exogenous phenomena that can lead to the planning being invoked.

3 Impact

3.1 Business Impacts

Traffic congestion has a dramatic impact on the economy and on businesses. In the UK alone, every year an average of 115 hours per driver (and approx. £ 1,000 per driver) are lost due to congestion, particularly in urban areas. This is then reflected in an overall damage of approximately £8 billion per year to the economy, due to delays and time wasted of commercial vehicles and fleets. Notably, this trend has not been mitigated by the COVID pandemic: traffic congestion has not been reduced, but has suddenly changed. In areas where a reduction in traffic due to commuters working from home has been recorded, overall traffic levels did not decrease significantly, due to an increased amount of commercial vehicles (deliveries, etc.) on the road to support the economy and the needs of the society.

The main sources of traffic congestion in urban areas are the suboptimal optimisation of traffic lights, that are using fixed strategies or reactive techniques based on simple traffic models, and the uneven distribution of traffic, that does not allow to exploit the entirety of the available infrastructure. Further, when unforeseen accidents happen, there is currently no automated technique that can allow to address the issue and mitigate the impact on traffic.

By improving the optimisation of traffic lights, and by providing a means to automatically generate traffic light strategies, it has been calculated that up to £3 billion could be saved annually in the UK only, due to reduced wasted time and improved quality of life. The quality of a traffic management strategy can be measured in terms of its impact on journey times, i.e. the time needed by vehicles to travel between different locations in a urban region. In some preliminary experiments, it has been shown that the use of optimised traffic light strategies can reduce journey times by at least 20%. Similarly, the effective routing of CAVs can reduce time wasted by at least 30%. It is expected that the synergies generated by holistically managing traffic lights and CAVs routing can further extend the beneficial impact of the approaches.

3.2 Other Impacts

Traffic congestion is a major health threat. In the UK alone, 64,000 deaths per year are linked to air pollution, for which a significant portion in cities is due to road transport, that leads to heart and lung diseases. It has also been

demonstrated the negative impact of traffic congestion on the brain system, that is linked to a significant increase of degenerative brain disorders in people living in congested urban areas.
The reduction of air pollution alone, that can be achieved via a smart optimization of traffic lights in urban regions, is expected to save up to 1,000 lives per year – with an indirect positive impact also on the overall wellbeing of people.

4 Measures of Success

The main measure of success in urban traffic control comes under the form of journey times. They are indeed used by traffic controllers to assess the level of service of a given urban region, and to decide if corrective interventions are needed. An objective indicator of the success of a planning application to urban traffic control is therefore the fact that journey times are reduced with regards to a considered (historical) baseline. In the presence of recurrent issues, when the planning system is invoked to respond to a phenomenon that has been observed historically, journey times resulting by the application of the planning-generated strategies are expected to be below those observed on historical data. In cases where a very unusual phenomenon is observed, the objective for a planning system would be to maintain journey times as close as possible to those observed with normal traffic conditions.

With regards to performance of the planning system, in the presented architecture it is expected to generate a strategy plan in less than 2-3 minutes. Shorter times, for instance below a minute, are particularly attractive as they can allow a traffic engineer to generate multiple strategy plans and compare their expected impact on the traffic conditions. The impact of generated strategies can be assessed via simulation.