Metaheuristic techniques for automated traffic light scheduling to minimize commute time

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1 Introduction and problem description

The Intersection Traffic Signal Control Problem (ITSCP) [5] serves as a model for optimizing traffic signaling in urban areas. Broadly, ITSCP comprises three primary components: the cycle, representing the overall time for a signalization period; the phase sequence, indicating the order of allocation of green time for individual incoming streets at the intersection; and the green time duration, encapsulating the total timings for a specific phase (i.e., incomming street), during which signaling remains constant [11]. In this extended abstract, we focus on a variant of ITSCP as defined in the Google Hash Code Competition [9], a competition that has been held annually from 2014 to 2022 [9]. This variant is characterized by a general network type that considers single vehicle types with a fixed scheduling strategy employing an offline scheduling mechanism. Additionally, the objective function aims to minimize delay for all vehicles, with no constraints imposed on cycle length, order of phase sequence, or green timing length for individual phases.

In summary, the problem revolves around intersections, streets, and cars, with intersections having at least one incoming and one outgoing street, streets connecting intersections without intersecting each other, and cars following predefined paths of streets, passing through each intersection at most once. Several hard constraints apply: green time is assigned to incoming streets one at a time, forming a repeating cycle until the simulation ends; cars wait at red signals and move through green signals, with only one car able to pass through an intersection per second during the green phase; the traffic light schedule determines the order and duration of green lights for incoming streets, ensuring each street appears at most once; all streets are one-way, preventing duplicate connections between intersections in the same direction; and cars start at the end of initial streets, adhering to traffic signals to reach their final destinations. The objective is to optimize traffic signal control, where each car earns points based on completing its route before the simulation ends, with a fixed reward for completion and additional points for early completion, and the overall solution score is the sum of all cars' scores. For a detailed problem description, please refer to the Traffic Signaling Problem in [9].

2 Solution approach

Our approach to solving the problem involves two main methods: one utilizes single-state metaheuristic techniques, specifically Iterated Local Search (ILS) [7], while the other employs population-based techniques, specifically a variant of the Evolutionary Algorithm (EA) introduced by Pham and Castellani [8]. ILS is well-known for its ability to avoid getting stuck in local optimal solutions, and it is also praised for being fast and memory-efficient, which has made it successful in solving various scheduling problems in transportation, such as last-mile routing [2] and the colored traveling salesman problem [12]. On the other hand, EA is known for its ability to escape from local optima, making it suitable for solving various combinatorial optimization problems [6], such as wireless sensor networks [1], the team orienteering problem with time windows [3], and shortest path problems with fuzzy arc weights [4].

A candidate solution of the envisioned ITSCP problem variant is represented by an array, with its length matching the number of intersections in the given problem. Within this array, each element is a tuple object containing information about the phase order and signaling time (green time) for each incoming street at the respective intersection. The search process always operates within the feasible part of the search space, where solutions are evaluated using a single objective evaluation function defined in the respective problem description [9].

Table 1: Implemented neighborhoods

Name	Description
ShufflePhases(i)	Rearrange the order of phases for the green signal timing for all incoming streets at intersection i
SwapPhases(i,s_1,s_2)	Swap the order of phases for the green signal timing for incoming streets s_1 and s_2 of intersection i
ChangeSignaling (i,s)	Change the green time for incoming streets s of intersection i

We have a set of three neighborhoods already implemented, listed in Table 1. In each iteration, these neighborhoods compete with each other based on specific probabilities assigned beforehand, which are fine-tuned based on initial experimentation.

3 Preliminary experimental results

We conducted preliminary experiments to evaluate the performance of our ILS and EA approaches. Both methods were tested against upper bound values (the hypothetical scenario where no car ever waits at the traffic lights) and Shporer's Greedy Constructive Algorithm (SGCA) [10], which is recognized as a top-performing approach in the literature.

Our experiments involved 48 instances, including 5 from the original Google Hash Code competition and 43 newly generated synthetic instances. These instances featured a variety of intersection, street, and car configurations to provide a comprehensive assessment.

Our findings indicate that both ILS and EA are competitive with the state-of-the-art SGCA approach. Notably, our methods achieved new best results for 12 instances. When comparing ILS and EA, EA outperformed ILS in 26 out of 48 instances, with superior results by more than 1% in 10 instances. These results demonstrate the potential effectiveness of our metaheuristic approaches for traffic light scheduling.

4 Future work

The current study represents an initial phase towards achieving a broader final objective. Initially, we intend to combine EA with ILS to assess the potential for achieving improved results. Additionally, we plan to integrate heuristic functions to guide the selection of promising intersections for adjusting the phase order or signaling time. Two potential heuristic functions we are currently implementing involve selecting intersections based on either the average length of the queue of waiting cars or the number of cars passing through them.

Furthermore, we are currently working on generating a new test based on real-life data acquired from a taxi company in the city of Prishtina, Kosova. This test set will be used to evaluate the current variant of the algorithm against state-of-the-art solvers.

As a final goal, we aim to extend the current problem definition to a setting suitable for real-life applications. To demonstrate proof of concept, the extended algorithm variant will be incorporated into a prototype web system. This system will be capable of generating traffic light schedules for Prishtina, Kosova, which has 25 intersections with traffic lights and nearly 300 street lanes connecting them.

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