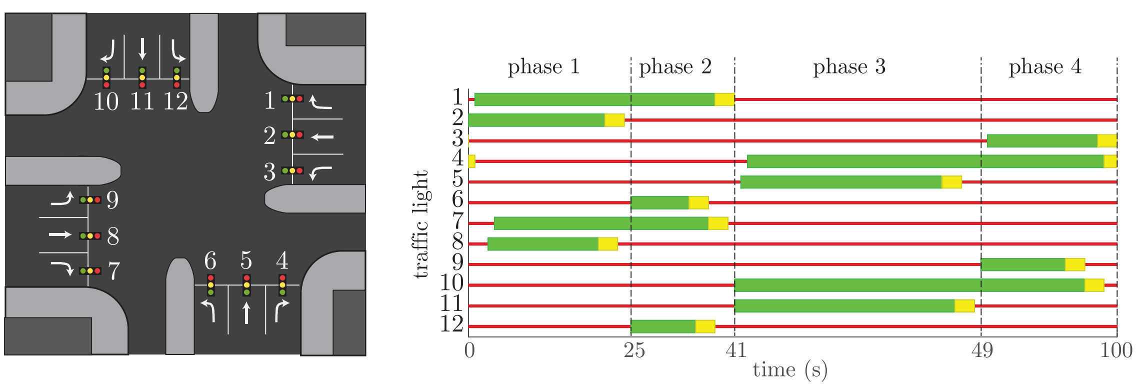
Summary

Optimizing pre-timed control at isolated intersections

Today's society has a large demand for road transport, which causes congestions in the road network. The consequences are serious: congestion increases the time we spend on the road, it affects our daily living, the quality of the air we breathe, the price tag on the products we buy, the costs of the trips we make, et cetera. In this thesis we develop several methods to take more efficient use of currently existing infrastructure and, as a result, these methods may also contributes to the mitigation of the congestion problem. To be more specific: this thesis concerns the optimization of pre-timed traffic light control at isolated intersections.



An intersection (left) and a signal group diagram (right).

For a pre-timed controller the green, yellow and red intervals are timed periodically. Such a controller can be visualized in a signal group diagram (see the figure above). In contrast to an actuated controller, the pre-timed controller does not use any detector information to control the traffic lights. Below we give a motivation for the optimization of pre-timed control

- Optimizing a pre-timed controller is usually the first step when designing an actuated controller; the traffic lights switch to green, yellow and red in the same order as the pre-timed controller, while the duration of these intervals depend on the current traffic situation.

- An actuated controller may behave as a pre-timed controller in some situations, e.g., when the amount of traffic arriving at the intersection is large. Such situations call for the design of a pre-timed controller.

- By optimizing a pre-timed controller (for an isolated intersection) we can check whether the intersection can handle the amount of traffic that is forecasted to arrive at it, i.e., we can check whether the intersection has enough capacity. This may also be used when designing an intersection, e.g., seeking for the intersection layout with the largest capacity.

- The 'predictability' of pre-timed control makes it easier to synchronize different intersections. As a consequence, the delay that road users experience can be reduced by synchronising the pre-timed controllers of the different intersections, which may create so called green waves.

- This predictability can also be used by 'smart' cars. For example by visualizing the future state of the traffic light. The road user can use this information to adjust its speed, reduce its waiting time and save fuel. Furthermore, this predictability can be used to compute a smart route through the city. This computation also includes the waiting time caused by traffic lights.

This thesis is structured as follows. First, in Chapter 2 we consider the mathematical modeling of traffic lights and the additional travel time (delay) that these traffic lights induce on road users.

This mathematical model is used in the subsequent chapters to optimize pre-timed controllers. First, in Chapter 3 we assume that each traffic light has a single green interval during one repeating period (see for example the signal group diagram given at the start of this summary). We optimize simultaneously: the period duration of the signal group diagram, when the green intervals start, and when they end. Possible objective functions are the maximization of the capacity of the intersection (i.e., search for the signal group diagram that can handle the largest increase in the arrival rates) and the minimization of the average delay that road users experience at the intersection. The proposed optimization problem is a 'mixed-integer programming problem'. The integral design variables of this optimization problem aggregate the binary variables of many known formulations. Based on an extensive numerical study, we conclude that this new formulation is superior to currently existing formulations. In other words, the needed computation time is much smaller for the novel formulation.

The proposed formulation is extended in Chapter 4 to also optimize the number of green intervals that each traffic light has. To this end, we use additional binary variables. Each of these binary variables switches 'on' or 'off' a specific green interval. To our

knowledge, this is the first formulation that also optimizes the number of green intervals of each traffic light. This allows us to optimize over a larger set of signal group diagrams and, as a consequence, find better signal group diagrams. From a numerical study we conclude that by also optimizing the number of green intervals, we are often able to reduce the average delay that road users experience by more than 10 percent.

In this thesis we also consider two extensions of the proposed optimization problem. In Chapter 5, we use the proposed formulation to optimize integral signal group diagrams. Each traffic light switches to green, yellow and red at an integral second for such integral diagrams. These integral schedules are desired in practice as they are clear, presentable and easy to work with. The proposed method consists of two steps. In the first step we optimize over the signal group diagrams that satisfy some structural property (which is also satisfied by each integral signal group diagram). The goal of this first step is not to find an integral signal group diagram yet, but to find a signal group diagram that can easily be 'rounded' in the second step. During the second step we round the signal group diagram obtained in the first step, by solving an optimization problem (mixed-integer programming problem). The result is the desired integral signal group diagram.

In Chapter 6 we consider an extension that allows us to also optimize the layout of the intersection, e.g., how many lanes does the intersection need, which of these lanes are arrival lanes, which lane-use arrows are marked on each of the lanes, et cetera. We can, for example, use this optimization formulation to answer the following questions:

- How should we change the lane-use arrows such that the capacity of the intersection is maximized?
- What is the smallest intersection that has sufficient capacity?
- Which possible intersection has the largest capacity?

To answer these questions, the layout of the intersection has to be optimized simultaneously with a signal group diagram.

Subsequently, in Chapter 7 we consider some practical issues that where not yet addressed in the previous chapters and, finally, in Chapter 8 we give our conclusions and recommendations.

With the different chapters of this thesis, we give an insightful and comprehensive overview of the optimization of pre-timed control and its usefulness. The methods proposed in this thesis can be used to aid traffic engineers in their process of designing a (pre-timed) traffic light controller (as well as their process of designing intersection layout).