Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 23 (2017) 612–623

Transportation Research Procedia

www.elsevier.com/locate/procedia

22nd International Symposium on Transportation and Traffic Theory

Adaptive offsets for signalized streets

Carlos F. Daganzo [a], Lewis J. Lehe [a], Juan Argote-Cabanero [a]

[a] *University of California, Berkeley, 416 McLaughlin Hall, Berkeley, CA, 94720, USA*

Abstract

This paper shows that severe congestion on streets controlled by traffic signals can be reduced by dynamically adapting the signal offsets to the prevailing density with a simple rule that keeps the signals' green-red ratios invariant. Invariant ratios reduce a control policy's impact on the crossing streets, so a policy can be optimized and evaluated by focusing on the street itself without the confounding factors present in networks. Designed for heavy traffic with spillovers, the proposed policies are adaptive and need little data – they only require average traffic density readings and no demand forecasts.

A battery of numerical experiments simulating the dynamics of rush hour traffic on a congested, homogeneous circular street reveals that the proposed form of adaptation reduces the duration of the rush and overall congestion compared with pre-timed control strategies. Eighteen different adaptation policies were considered. All inspect the street densities periodically and simulataneously, and retime the signals immediately thereafter. The period is a fixed multiple of the cycle. The street is evenly divided into sections that contain a set number of consecutive blocks and signals. The offset is the same for all blocks in a section. Three inspection intervals and six section sizes were tested. The latter ranged from a single block/signal to the whole street.

It was found that adaptation worked best when sections were large and adaptation frequent. The effects were considerable across all scenarios. For a short street with a short rush and high input flows the probabilistic incidence of gridlock was reduced from 10% to 0%, and the average duration of a trip from 216s to 181s. For a long street with a long rush and high input flows the gridlock probability was reduced from 23% to 0% and the average trip duration from 2037s to 1143s.

Peer review under responsibility of the scientific committee of the 22nd International Symposium on Transportation and Traffic Theory.

Keywords: ISTTT22, traffic signals, adaptive offsets, MFD, congestion

1. Introduction

Traffic signal settings for urban networks are difficult to optimize because the equations that describe the response of the traffic system to control actions, especially under congested conditions, are notoriously complex: they are mixed-integer, non-linear and exhibit time-memory. Perhaps for this reason, the scientific literature on the topic is of an exploratory nature. Much of it focuses on pretimed plans, tested under favorable conditions involving known demand and vehicle routings (Lo, 1999 and 2001, Lo and Chow, 2004, Li, 2011, Hu et al, 2013, Han et al, 2016, and Wada at al, 2016). The results from all these works are quite promising.

It is therefore valuable to see whether their promise can be maintained by adaptive schemes that are less reliant on demand forecasts. Two recent works explore this idea (Zhang et al, 2013, and Gayah et al, 2015). A core idea

---

* Carlos F. Daganzo, daganzo@berkeley.edu

2352-1465

Peer review under responsibility of the scientific committee of the 22nd International Symposium on Transportation and Traffic Theory.
10.1016/j.trpro.2017.05.034

of both proposals is that green time should not be wasted on undersaturated approaches – both references propose heuristic rules to dynamically apportion the green phases of a network's intersections based on the congestion status of thier approaches. As one might expect, given that intersections are used more efficiently with adapted greens when a network is congested, both references find notable improvements in congested networks.

The question that motivates this work is whether further improvements can be obtained if, in addition to green time, adaptation also considers signal *offsets* (the time between the green phase starts of consecutive signals). Offsets, after all, are known to influence both the flow (Gartner and Wagner, 2004) and capacity (Daganzo and Lehe, 2016) of single streets – in fully congested links, offsets influence whether holes arrive at the links' upstream ends in time to absorb discharging vehicles from the upstream signals. Offset control could be particularly useful on streets that are already receiving as much green as is feasible.

With this in mind, and as a proof of concept, this study examines a simple scenario that isolates the effect of adaptive offsets: a single one-way street with time-dependent demand but fixed cycles and signal phases. The control policies will be forecast-free and adaptive. Offsets will be changed while keeping the green ratios of every intersection fixed. In this way the control policy should not disturb much the rest of the network, so the street can be studied alone. The only state variables will be the average densities observed in different parts of the street, which can be observed either directly or indirectly.[1]

The paper's specific objective is understanding how offset adaptation affects the growth and dissipation of congestion on one-way streets with time-dependent input flows. It is assumed that inputs arrive from side streets and garages and that vehicles also exit on side streets and garages. Vehicles are endowed with specific destinations so that the percent of exits in a block is a result of the vehicles' travel, and is not pre-specified. All the exit points are assumed to have enough capacity to admit the exit flows so exit queues do not spill back onto the street. The hope is that the findings obtained under these idealized conditions can inform more comprehensive studies for two-way streets and networks.

The work builds on recent advances in the estimation of steady-state flows for signalized arterials (Daganzo and Geroliminis, 2008, Leclercq and Geroliminis, 2013, Laval and Castrillon, 2015, Daganzo and Lehe, 2016). We use in particular the last reference, which gives an exact formula for a signalized street's MFD and characterizes how its aggregate flow depends on both its aggregate density and the signals' offsets. The formula establishes that: (i) the aggregate flow can be maximized across all possible densities with a small menu of offsets, and (ii) that poorly-chosen offsets reduce flows considerably. If these results also apply in the dynamic case, then adapting the offsets would also raise the aggregate flow in the dynamic case. This would increase exit rates and lower the total vehicle-hours traveled during the rush. The latter shall be a metric of interest, along with the probability of gridlock.

In order to see whether offset adaption works and quantify its potential, if any, the paper is organized as follows. Section 2 describes the analyzed system, section 3 the control strategies, section 4 the evaluation procedure, and section 5 the results. The paper concludes with a brief discussion that addresses possible extensions.

2. The Analyzed System

As in Daganzo and Lehe (2016) we choose the simplest system that exhibits the phenomenon of interest: a single one-way, closed-loop street of length L composed of identical blocks with identically timed signals. The number of blocks/signals is fixed at M = 32. This number is chosen because it is a power of 2. The ring can then be evenly partitioned in 6 different ways, using $s = \{1, 2, 4, 8, 16, 32\}$ identical sections of $\{32, 16, 8, 4, 2, 1\}$ blocks each.

The signal timings are now defined. The testbed is intended to be an arterial street that intersects M minor streets. The arterial's blocks are numbered $m = 1, 2, ...M$, increasing in the direction of traffic flow. The intersections at the ends of these blocks are controled by traffic signals with a common cycle, $C = 54$s, and the same green-cycle ratio, $G = 2/3C$, so that $G = 36$s. The green-cycle ratio is the same as in Daganzo and Lehe (2016). Since we believe that small changes to C and G/C should only have a minor impact on how the control strategies perform, G and C will not be varied in the paper.

---

[1] Density can be estimated indirectly from the average speeds observed in the street; e.g., with applications such as Google Maps.