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Capacity optimization of an isolated intersection under the phase swap sorting strategy

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ABSTRACT

It is well recognized that the left turn reduces the intersection capacity significantly, because some of the traffic lanes cannot be used to discharge vehicles during its green phases. In this paper, we operationalize the phase swap sorting strategy (Xuan, 2011) to use most, if not all, traffic lanes to discharge vehicles at the intersection cross-section to increase its capacity. We explicitly take into consideration all through, left- and right-turning movements on all arms and formulate the capacity maximization problem as a Binary-Mixed-Integer-Linear-Programming (BMILP) model. The model is efficiently solved by standard branch-and-bound algorithms and outputs optimal signal timings, lane allocations, and other decisions. Numerical experiments show that substantially higher reserve capacity can be obtained under our approach.

1. Introduction

One of the major objectives in traffic signal optimization is to increase the capacity of at-grade intersections (Improta and Cantarella, 1984). Literature in this field can be broadly classified into two streams: The first stream develops optimization models to determine optimal lane allocations, signal phases, and signal timings for conventional intersections. Early research in this stream includes Webster (1958) and Allsop (1972), which are later extended to group-based methods where traffic movements are grouped into phases (Improta and Cantarella, 1984; Gallivan and Heydecker, 1988; Silcock, 1997), and more recently to lane-based methods where lane allocations are simultaneously optimized (Wong and Wong, 2003; Wong and Heydecker, 2011). The second stream of research recognizes the fact that the left turn significantly reduces the capacity of conventional intersections, because it often requires separate green phase allocation, during which only part of the intersection cross-section can be used to discharge vehicles (Newell, 1989). Researchers have therefore proposed a variety of ways to ban and re-route left-turning vehicles at such intersections, for example, median U-turns, jug handles, superstreets and so on (Reid, 2004; Rodegerdts et al., 2004). These strategies increase the intersection capacity by eliminating the left turns and the need for left turn phases.

Recently, the sorting strategy, a class of methods belonging to the second stream of research, has emerged as a promising new way to mitigate the negative impact of the left turn. In this strategy, pre-signals are used to re-organize traffic upstream of the intersection, so that the entire intersection cross-section can be used to discharge vehicles during left turn phases. Xuan et al. (2011) proposes the *tandem sorting strategy*, where a pre-signal is installed upstream of the intersection signal (see Fig. 1), which forms a *sorting area* between the pre-signal and the intersection signal. Upstream of the pre-signal, lanes are marked by movement to segregate left-turning vehicles (LVs) and through vehicles (TVs) onto separate sets of lanes. In

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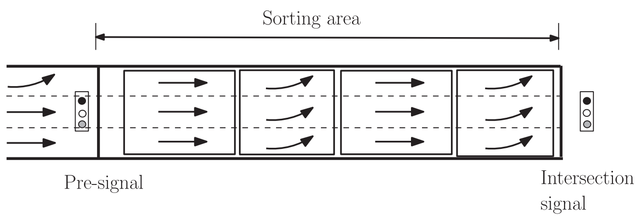

Fig. 1. The tandem sorting strategy proposed by Xuan et al. (2011).

this example, the first set contains one lane for LVs and the second one contains two lanes for TVs. Right-turning vehicles (RVs) are not shown for simplicity of exposition. The pre-signal operates on the same cycle as the intersection signal and gives green time to the two sets of lanes alternatively. When the LVs or TVs advance into the sorting area, they use all the lanes so that when the intersection green phases start, all lanes can be used to discharge vehicles during both through and left turn phases. LVs and TVs are asked to form tandem batches and parade through the sorting area as well as the intersection cross-section using all lanes. In this way, the intersection capacity can be improved. Later, Xuan et al. (2012) present empirical evidence from an intersection in the city of Chengdu, China to prove its effectiveness. More recently, Zhou and Zhuang (2013) develop an optimization model to minimize the delay associated with this strategy and output optimal lane allocations and signal timings.

In an effort to reduce the length of the sorting area, Xuan (2011) proposes the *phase swap sorting strategy* where only a single batch of LVs or TVs are allowed to queue in the sorting area. This strategy is illustrated in Fig. 2: In Fig. 2(a), the pre-signal starts its cycle by giving the green to LVs while the intersection signal is red to allow LVs to enter the sorting area and wait at the intersection stop line on all lanes. In Fig. 2(b), the pre-signal turns red for LVs and the intersection signal turns green to discharge LVs queued in the sorting area until the sorting area is clear of vehicles. In Fig. 2(c), the pre-signal turns green for TVs to allow them to enter the sorting area and wait at the intersection stop line on all lanes. In Fig. 2(d), the pre-signal turns red for TVs and the intersection signal turns green to discharge TVs queued in the sorting area until the sorting area is clear of vehicles. The operation on this arm then returns to Fig. 2(a) and repeats the above steps. We want to point out that besides the capability to work with a short sorting area, the phase swap sorting strategy has another important advantage for easier compliance than the original tandem sorting strategy. The phase swap sorting strategy no longer requires vehicles to form tandem batches and parade through the sorting area, which may be difficult, if not impossible, to happen due to the heterogeneity in car following behavior among drivers. When drivers follow vehicles with different speeds and spacing, the boundaries between adjacent batches will become irregular or even disappear, causing disruptions to the system.

The goal of this paper is to operationalize the phase swap sorting strategy and develop an optimization model that produces capacity maximization decisions. We first propose an operational paradigm for the phase swap sorting strategy that coordinates the pre-signals on all arms and the intersection signal. We then generalize the strategy to explicitly take into

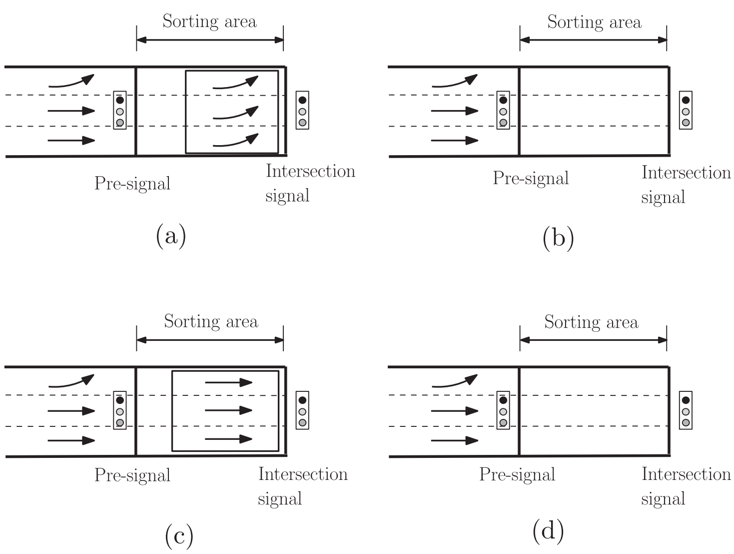

Fig. 2. The phase swap sorting strategy proposed by Xuan (2011). (a) LVs advance into the sorting area. (b) LVs are discharged from the sorting area. (c) TVs advance into the sorting area. (d) TVs are discharged from the sorting area.