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Increasing the capacity of signalized intersections with left-turn waiting areas

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ABSTRACT

One of the most complex issues for the design of at-grade signalized intersections is accommodating left-turn (LT) movements, especially when approaches have insufficient available spatial resources. In this study, we mitigated this problem by reorganizing left-turning traffic flows within intersections through the use of a left-turn waiting area (LTWA). We proposed a series of design pattern left-turn waiting areas for different combinations of spatial and temporal treatments of left-turn movements: exclusive left-turn lanes with protected left-turn phasing, exclusive left-turn lanes with permitted left-turn phasing, and shared left-turn lanes with permitted left-turn phasing. Based on probability theory, an analytical procedure is developed for estimating the capacity of shared and short lanes. Explicit VISSIM simulations are conducted to validate the accuracy of the proposed capacity models, and the impact of design parameters for the proposed system on the left-turn capacity are studied. On the basis of the analyses, benefits of the proposed system are identified, and the domain of application where these benefits are most significant is identified. In addition, optimal LTWA design scheme and critical LT volumes of exclusive LT lane and protected LT phase with different LTWA schemes are presented from the operation efficiency perspective.

1. Introduction

Maximizing the potential capacity of existing roadways has become a priority in light of growing traffic demand and diminishing resources to develop more capacity (Li, 2011; Ma et al., 2014; Yin, 2008; Yu and Recker, 2006; Zhang et al., 2013). One of the most complex issues for increasing the capacity of at-grade signalized intersections is accommodating left-turn (LT) movements on all approaches efficiently. In some cases, LT movements may create a negative impact on the efficiency and even safety of traffic operations if not treated properly (Xuan et al., 2011).

At a typical four-legged signalized intersection under light LT demand conditions, the optimum signal timing plan normally involves two phases; left-turning vehicles (LVs) and through-going vehicles (TVs) share one phase during which left turning is permitted. If there is a sufficient number of LVs, a protected LT phase is typically introduced at signalized intersections to handle the flow (Oppenlander and Oppenlander, 1989; Zhang et al., 2006). This is considered the most effective way to provide safe traffic operations and handle large LT volumes with less delay (Al-Kaisy and Stewart, 2001). Several studies have suggested that potential criteria for selecting the protected LT phase fall into five categories: delay, traffic volume, crash/conflict experience, speed, and intersection geometry (Lin and Machemehl, 1983).

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Besides the signal phase and timing optimization, problems with LT traffic can also be addressed in the geometric design of intersections (Wong and Wong, 2003). According to Ousama's research, exclusive LT lanes play an important role in the effective organization of intersections. Kikuchi and Oppenlander (Oppenlander and Oppenlander, 1989; Kikuchi et al., 1993) developed methodologies to determine recommended lengths of LT lanes at signalized intersections. They concluded that the LT length is related to the traffic volume, geometry, and intersection control type. The impact of the spatial distribution of LT lanes (inside and outside an approach) was evaluated by comparing turning speeds and saturation flow rates for LVs (Liu et al., 2011; Yang et al., 2012).

Previous works have focused on estimating the capacity of LT lanes. Lin provided logical explanations for the causal relationships between the capacity and saturation of a shared LT lane and governing variables such as the number of opposing lanes, opposing flow rate, proportion of LT traffic in opposing lanes, proportion of LT traffic (Lin, 1992), and the critical gap on the secondary road (Pollatschek et al., 2002). Al-Kaisy and Stewart (2001) discussed three scenarios involving exclusive LT and shared-lane operations and presented an argument for adding protected LT phases at signalized intersections that previously used permitted-only LT operation. Wu investigated the capacity of minor stream at an unsignalized intersection (Wu, 2001), and the capacity of shared short lanes at a signalized intersection in simulation studies (Tian and Wu, 2006). The approach capacity with a short LT lane was found to be specifically related to the length of the short lane, the ratio of turning vehicles, and the green times for both through-going and turning vehicles. Based on different combinations of the signal phase and lane distribution, HCM 2010 classifies LT traffic flow into six types to calculate the correction coefficient of the saturation flow rate (Transportation Research Board, 2010).

In large numbers, LVs contribute to oversaturation because they require separate green phase allocations, and these sub-phases reduce intersection capacity (Xuan et al., 2011; Zhao et al., 2015). These capacity problems are often avoided in practice by banning and rerouting the offending LVs (Zhao et al., 2014). These strategies are effective because they eliminate LVs and the need for LT lanes and phases, which increase intersection capacity. However, with these strategies, LVs need to make a detour in the road, which will increase the traffic flow in the network accordingly. Hence, the performance of these strategies depends on the geometric characteristics and demand patterns of the network. The implementation of these strategies usually involves construction and requires a substantial amount of space that may not be available.

Based on these challenges, this paper proposes a method to increase capacity by the proper design of the left-turn waiting area (LTWA) within an intersection. The implementation of this strategy does not require banning left turns or reconstructing the intersection. The proposed strategy focuses on making full use of the spatial resources of an intersection.

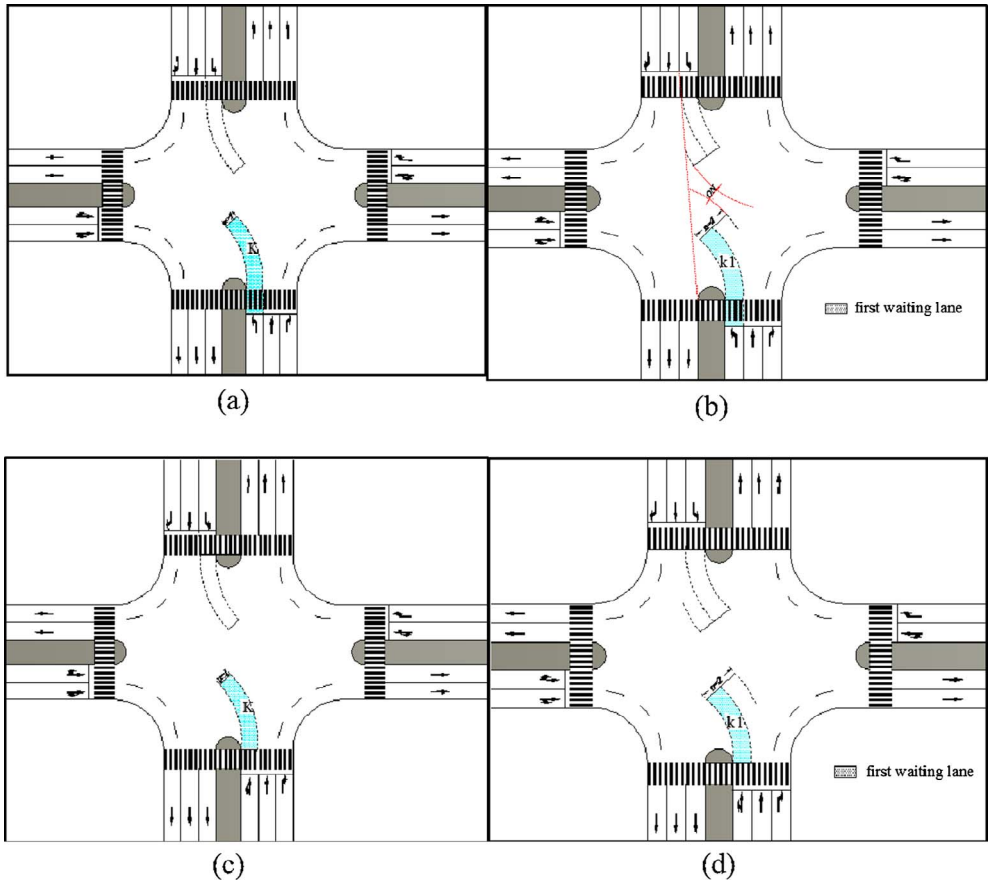

Fig. 1. Layouts of LT lanes and LTWAs.