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Optimization of pedestrian phase patterns and signal timings for isolated intersection

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ABSTRACT

This paper establishes quantitative criteria for selecting pedestrian phase patterns between the exclusive pedestrian phase (EPP) and the normal two-way crossing (TWC) with both safety and efficiency factors traded-off in an economic evaluation framework. The safety effect is assessed by modeling the number of pedestrian-vehicle exposures and pedestrian violations (i.e., pedestrian noncompliance) based on the traffic conflict technique (TCT); and the operational efficiency is measured with a new model considering pedestrian delay due to signal, conflicts, and detour. Both safety and efficiency performance indices are converted to monetary values in an integrated model to simultaneously select pedestrian phase patterns and optimize signal timings of an intersection with two phases. Case study results have shown the promising property of the proposed approach to assist transportation professionals in properly selecting pedestrian phase patterns at signalized intersections.

1. Introduction

Pedestrianism is becoming more and more popular due to growing concerns for sustainable development, environment pollution, and energy crisis. On the other hand, the trend of vehicle-miles of travel is increasing rapidly particularly in developing counties. A critical problem at signalized intersections is how to deal with conflicting movements, such as balancing the needs between pedestrians and vehicles. Traffic engineering researchers and practitioners have long been seeking solutions to make a best tradeoff between vehicular and pedestrian traffic in terms of efficiency and safety. In practice, the delay incurred by pedestrians is usually not considered in the design of pedestrian crossing control strategies. Recent trends in developing pedestrian friendly urban areas have prompted the interest in reexamining the engineering methods typically used to control pedestrian flows (Boudet and Midenet, 2009; Carsten et al., 1998). More specifically, ways to reduce pedestrian delay and to make safer pedestrian environments are becoming effective means to increase walk ability in cities (Kasemsuppakorn and Karimi, 2013; Kneidl et al., 2013). The exclusive pedestrian phase (EPP) is designed to display the red signal for oncoming vehicular traffic at all approaches so that pedestrians can cross the intersection in all directions (diagonally as well as laterally) at the same time (Kattan et al., 2009). By increasing the convenience in pedestrian crossing, the EPP is effective to promote walking around the downtown area and encourage motorists to park and walk to destinations.

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The EPP has been used for decades in many cities, and studies have been published on their usefulness since the early 1950s. A number of studies have been done on selection and design of the EPP, falling into two major categories: safety-based studies and efficiency-based studies as summarized in (Ma et al., 2013).

Many studies argue that EPP can be used to improve safety as all conflicts between vehicular and pedestrian movements are eliminated (Zegeer et al., 1982). The safety benefit from eliminating the conflicts between pedestrians and vehicles has been estimated to range from 7% to 63% in terms of reduced crashes (Jensen, 1999), and 66% by another study over a ten year period (Vaziri, 1989). Improving pedestrian safety by elimination of conflicts, however, succeeds at the cost of degradation of traffic flow conditions (Kim et al., 2004). Moreover, pedestrian compliance plays an important role in the successful operations of the EPPs. They are proven to be very safety-beneficial in a small town, while in a large town they are not as effective because of very low pedestrian compliance rates (Garder, 1989). Studies have demonstrated an increase in the number of pedestrian violations after implementation of the EPP crossing (Bechtel et al., 2003). Abrams and Smith (1977) contended that under frequent violations, the use of EPP timing may be more of a safety hazard than an accident prevention measure. Moreoever, they reported that observations from several EPP intersections revealed that violations were more frequent on narrow streets (Abrams and Smith, 1977).

In the category of efficiency-based studies, one major concern about EPP is its increase in vehicle and pedestrian delay due to its requirement of long signal cycles (Huang and Zegeer, 2000). The use of EPP is beneficial where significant pedestrian activities and high turning traffic volumes exist (Tian et al., 2001). The EPP phasing plans increase capacity in the nearside turning lanes (left turn in left hand drive conditions and vice versa), as turning vehicles are not blocked by parallel pedestrian traffic. However, Abrams and Smith (Abrams and Smith, 1977), after analyzing a hypothetical intersection with EPP and parallel pedestrian phasing, found that vehicular delay in through lanes and the pedestrian delay increased to over 200% for the EPP crossings as compared with normal two-way crossing (TWC). On the other hand, EPP crossings reduce the distance that pedestrians must travel to cross two arms of an intersection, resulting in an added convenience. The EPP study in Chinatown, Oakland, showed that EPP reduced the distance traveled by pedestrians by 13%, but did not maximize vehicle capacity for the intersection nor did it minimize delay to users (Bechtel et al., 2004). With a computer simulation model, Marsh (Marsh, 1982) found that EPP signalization would result in 5% to 7% reduction in distance traveled by pedestrians at several intersections in New Zealand.

In summary, besides traffic safety concerns, the EPP and TWC approaches both have advantages and disadvantages in term of efficiency. The EPP crossing may cause longer waiting time for through and turning vehicular traffic and pedestrians. Some traffic engineers do not suggest the use f EPP except for unusually high pedestrian volumes. However, at an intersection with high volumes of right-turn vehicular traffic and pedestrians, the EPP crossing can eliminate the conflicts between them, thereby improving the capacity for the right-turn lane group and reducing the delay for pedestrians. In contrast, the TWC, in general, reduces the delay for through and turning traffic and pedestrians as compared to the EPP crossing, but it is not suitable at high-volume intersections especially with large volumes of right-turn traffic and pedestrians.

Currently, the pedestrian phase patterns are usually selected by engineering judgment. Only limited studies have been undertaken to establish quantitative criteria to select the appropriate pedestrian crossing phase patterns. For example, the Highway Capacity Manual 2010 does not discuss the conditions that warrant EPP. In this regard, a method has been proposed to determine the suitability of EPP based on the weighted pedestrian and vehicle delay (Zengyi and Benekohal, 2011). However, the pedestrian delay under EPP and TWC control are not explicitly modeled, and the weights for pedestrian delay and vehicle delay have not been justified. In addition, previous studies do not explicitly consider the trade-offs between safety and delay of pedestrian and vehicular traffic, possibly resulting in both unsafe and inefficient performance at the intersection.

This study, proposed to address the above problem, establishes quantitative criteria for selecting pedestrian phase patterns between the EPP and TWC approaches while considering both safety, efficiency, and their trade-off in an economic evaluation framework. The safety effect is assessed by modeling the number of pedestrian-vehicle exposures and traffic accident accordingly, whereas the operational efficiency is measured with a new model considering pedestrian delay due to signal, conflicts, and detour. Both safety and efficiency performance indices are then converted to monetary values in an integrated model to simultaneously select the pedestrian phase pattern and optimize the signal plan for an intersection.

2. Problem description and model formulation

2.1. Problem description

As introduced in the previous study (Ma et al., 2013), unlike the normal TWC phase design (see Fig. 1a and c, the dot arrows show the pedestrian phases; the solid arrows show the vehicle phases), the EPP provides pedestrians with exclusive access to the intersection by allowing both the conventional two-way crossing (north–south and east–west) and diagonal crossing at the intersection when vehicle traffic is stopped on all approaches (see Fig. 1b and d). Although there are several other types of operations combining the EPP and the TWC, the one shown Fig. 1b is the most commonly used (Kattan et al., 2009). For simplicity of illustration, this study only considers an intersection with two signal phases. However, the proposed framework can be easily extended to a multi-phase (e.g. with protected left turn phases) intersection by adding additional decision variables into the optimization model.